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SCHEDULING OPTIMISATION UNDER CONTRADICTIONS IN CRITERIA FUNCTIONS

Introduction

The theory of scheduling is characterized by a virtually unlimited number of problem types. Scheduling optimisation problem is encountered in several fields, not only such as airline, rail, school bus and urban transportation, but also in all types of parallel systems, especially in parallel computing. The tasks of constructing a schedule arise whenever there is a choice of one or another order of execution of works. Often, such tasks are solved by a simple arrangement of works in the order of their receipt into the system, and sometimes by chance or intuitively. The problems of creation optimal schedule are quite complex. As a rule, the criteria of optimality contradict each other. The basic types of scheduling are of deterministic or stochastic types. Such and more complex models involving flexible schedules, different carrier types, and other generalizations, are treated by the methods of computer modelling and simulation.

For example, the major objective of any task-scheduling algorithm is to minimize the overall scheduling length. Besides, sometimes we must consider resource constrained scheduling problems with known deterministic renewable resource orders but uncertain and stochastic activity durations.

Here we consider the problem of scheduling optimisation in one stage system with single depot and a set of *N* trips.

Analysis of recent research and publications

In the literature, a number of previous work for scheduling of transportation, communication, and other systems have been done, which address the scheduling design challenges in different aspects. The theory of scheduling is characterized by a huge number of problem types (see, e.g. Baker [1], Blazewicz et al. [2], Tanaev et al. [3], Sinnen [4], Pinedo [5] etc.). In this paper, a regular approach for the scheduling problems is covered. This approach is based on a scheduling scheme extended with original setting to carry out the various activities.

Most of the scheduling problems are combinatorial in nature [6–9]. One of the major challenges faced by high-end computing machines or supercomputers, which are widely used in scientific computing area, is energy and power efficiency [10]. A promising way to improve the energy and power efficiency is to employ the low-power architecture developed for optimal scheduling. The experimental results show that the scheduler can manage the thread running with lowers overhead and less storage order, thereby, improving the multi/many-core system performance. However, for fine-grained scientific workload, data communication is more complicated. Other researches are mainly concerned about the runtime scheduling algorithms, which assure the maximum system throughput with acceptable system cost.

Problem statement

In this paper we will follow two guidelines. One guideline is a distinction between scheduling models, which comprise a set of scheduling problems solved by dedicated algorithms. Thus, the aim of this paper is to present scheduling models for parallel processing, problems defined on the grounds of certain scheduling models, and algorithms solving the scheduling problems. Therefore, the second guideline is the methodology of computational complexity research.

In the scheduling theory, the focus is on the optimal distribution of the finite set of orders serviced by deterministic systems with one or more devices, with different assumptions about the nature of their service. Consider a set of *N* trips $\left\{\Im_1\left(\tau_i\right),\Im_2\left(\tau_j\right),\ldots,\Im_N\left(\tau_K\right)\right\}$, where trip $\Im_i\left(\tau_j\right)$ has a given duration τ_j and starts at time τ_l, $l=1,2,\ldots,L$. Consider also a single depot where *v* objects are stationed. Let the set of nodes, *n* = {1, 2, . . ., *N*} represent the set of trips, and node $\left[n+1\right]$ represents the sink depot.

All information on the basis of which decisions are made to organize the tasks of the scheduling system (time, cost, implementation constraints, required resources) is known in advance, so the model of such a system is deterministic. The model of the process of constructing a schedule is a set of models that describe the resources, system of tasks, constraints on the construction of those evaluation criteria. The service devices in most systems are considered as resources, and the tasks or orders, are performed trips.

A serving system is called one-stage (with one or more parallel devices) if each order can be fully serviced by each of the M devices. Durations τ_j servicing each order $i \in N$ by each device $1 \leq M \leq L$ are preset.

In multi-stage systems, the process of service i^{th} order includes $r_i \geq 1$ consecutive steps. In this case, every order of each stage $1 \leq q \leq r_i$ of its service a certain set of devices is compared to. The i^{th} order and at the q^{th} stage can be served by any device $L \in M_q^{(i)}$.

Despite the fact that the service of the order can be regarded as a certain sequence of processes (information pick-up, preliminary preparation, loading of service objects, processing, preparation to completion, ending, etc.), it is worth to represent it as a whole within the scheduling. Consequently, the fulfilment of one order is carried out in this case by one device, and thus it can be argued that the scheduling system of the scheduling is one-stage.

Depending on the nature of the service system, the process of service orders of the device must either proceed continuously, or interrupts may be allowed with subsequent final servicing orders. In scheduling without interruptions, the task cannot be interrupted once it starts, that is, the task is always completed. Otherwise, when scheduling with interrupts, it is allowed to interrupt the task and remove it from the device, while it is assumed that the total time required to complete the task remains unchanged, and at interruptions there is no loss of service time (that is, the execution of the interrupted task is restored from that place, in which there was an interrupt).

There is another approach to creating a schedule - compiling it using a list. This method involves the preparation of an ordered list of N tasks. This list is often referred to as a list of priorities [11]. The sequence according to which tasks are assigned to the devices is made by repeatedly reviewing the list. In particular, if a released device appears, the list begins to be viewed first and is viewed until there is a first unfulfilled task i ready to execute. The task is considered to be ready for execution on this device if the execution of all the predecessors i is complete and the available amount of resources is sufficient to provide the required amount of resources for execution. This task is intended for execution on a free processor. When viewing a list of interruptions are not considered. Thus, schedules compiled using the list form a subset of schedules without interrupts.

Formation of a schedule with the help of a list is a very interesting tool in the case of a flight schedule, since its efficiency is based on many criteria that are easily presented as a list of priorities. Among such criteria are time parameters (time of parking and joints, time of flight in a certain direction, prevailing flight time in relation to time of day and to parallel flights in a certain direction), parameters related to type of aircraft (number of passenger seats, range flight, noise level limitation for certain aircraft engines), etc. The list of such criteria is widely used by commercial airline companies when planning flights and assessing their quality.

In addition to the permission or the prohibition of interruptions, other orders that arise from the statement of the specific task under consideration may be submitted to the schedule. For each order, a time of di≥0) of its entry into the system (in the queue for service), from which it can be served, and a policy term Di≥0, to which it is necessary or desirable to complete its maintenance, can be set. [2] There are tasks in which policy tasks should not be violated. Then they are called extreme terms.

Mathematic model of scheduling and estimation scheduling quality

Two or more devices cannot service each order simultaneously and each device cannot simultaneously serve more than one order. In this case, the assumption of a schedule can be considered as a vector $\mathbf{S}^{\mathrm{T}} = \{s_1(t), s_2(t), \ldots s_M(t)\}$ of piecewise continuous from the left side functions $s_L(t)$, $L \in \overline{1,M}$, each of which is given on the interval 0≤ t <∞ and accepts values $0,1,\ldots,n$. If $s_L(t') = i \neq 0$, then at time $t = t'$, device L serves i^{th} order. If $s_L(t') = 0$, at time $t = t'$ the device L is idle. Sometimes, instead of the functions $s_L(t)$, $L \in \overline{1,M}$ describing the functioning of each device, similar functions $s_i(t)$, $i = \overline{1,n}$, describing the process of servicing each order. (si (t ') = 0, If at time $t = t'$ i^{th} order is out of service, $s_i(t') = 0$, and if at the time $t = t'$ the order is served by the device L, $s_i(t') = L$.

The most common way of evaluating scheduling quality for deterministic service systems is as follows. Each schedule S corresponds to the vector

$\mathbf{T}(s)=\{\overline{t}_1(s),\overline{t}_2(s),\ldots,\overline{t}_n(s)\}$ of moments of completion of service orders in this schedule. A real non-decreasing function of *n* variables $F(\mathbf{X})=F(x_1,x_2,\ldots,x_n)$ is given.

The quality of the scheduling s is characterized by the value of this function when $x=\overline{t}(s)$. From the two schedules, the one that corresponds to the smaller value of $F(x)$ is preferred.

The schedule, which corresponds to the smallest value of $F(x)$ (among all acceptable schedules), is called optimal.

When a function $F(x)$ is assigned to each order, and as a rule, compare some monotonically increasing criterion function φ (t), which represents a quantified loss, if the service of this order is completed at time *t*.

The quality of the scheduling s is characterized by the total or maximum cost that needs to be made in service the orders of this schedule:

$$F_\Sigma=\sum_{i=1}^{n}\varphi_i\left(\ \overline{t}_i(s)\ \right)\quad\text{or}$$

$$F_{\max}(s)=\max_{1\le i\le n}\left\{\ \varphi_i(\overline{t}_i(s))\ \right\}.$$

In particular, if $\varphi_i(t)=t,\ 1\le i\le n$, i.e. $F_{\max}(s)=\max_{1\le i\le n}\{\overline{t}_i(s)\}$ is the moment of completion of service of all orders (total service time). In this case, $F_{\max}(s)$ is denoted by $\overline{t}_{\max}(s)$, and the schedule s* delivering the smallest value is called the optimal speed rate [3].

Often, the schedule performance indicators are the length of the schedule or the maximum (or average) time of its pass [1].

In the case of constructing a schedule for the movement of aircraft, the criterion of its quality cannot be its length, or the passage time, because its optimality is achieved, primarily, not because of a quick execution or a shorter path.

The effectiveness of such a schedule is due, rather, to a certain distribution of flights within a day, the compliance of the PS with the tasks that it must perform, the manipulation of the time of arrival and departure of transit flights, etc.

Therefore, an assessment of the quality of a schedule based on its length or timing of the schedule is not appropriate in the case of computer or manufacturing processes schedules [2].

The way out of this critical situation is combination of penalty functions and compromises with using priority attributes [11].

Conclusions

The possibility of combining the methods of the theory of decompositions and the method of compromise procedure is based, in essence, on the natural intrinsic unity of these methods. Due to this, it is possible, firstly, to take into account formal and informal indicators of optimality, and secondly, to reduce the dimension of the optimisation problem. This allows for modification of the schedule at the current time scale.

Penalty functions for the problem under consideration can be either linear, or (more often than not) lump-linear or non-linear. By such penalty functions, you can successfully use the standard algorithms of the sequence of unconditional optimisation tasks. The length of this sequence depends on a successful selection of penalty functions.

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ОПТИМІЗАЦІЯ РОЗКЛАДУ З СУПЕРЕЧЛИВИМИ КРИТЕРІЯМИ В ФУНКЦІЯХ

У статті розглянуто аналіз методів побудови розкладу виробництва, заснованих на теорії планування. Показано, що найефективнішим кроком в цьому процесі є оптимізація діяльності авіапідприємства на всіх рівнях – економічному, технічному, інформаційному, та ін. Оскільки оптимізація планування розкладу займає принципово важливе місце в процесі організації ефективної діяльності авіакомпанії, розглянуто можливості використання цієї теорії при створенні оптимального графіка для середніх і великих організацій.

Розглянуто задачу оптимізації планування в одностадійній системі з єдиним накопичувачем та набором N сервісів. З метою впорядкування критеріїв оптимальності розкладу для забезпечення зручності описання, зберігання та програмного втілення,запропоновано умовний поділ критеріїв на географічні, технічні або транзитні категорії з описом відповідного значення пріоритету. Запропоновано метод пріоритизації критеріїв по різним категоріям, заснований на теоретичному підґрунті аналізу ієрархій Сааті, модифікованому для даної конкретної задачі.

Встановлено, що зі змінами ситуації на ринку виробництва, логістики, нормативно-правового та економічного забезпечення по-різному змінюються зміст та відносна важливість самих критеріїв. З математичної та логічної точки зору це означатиме зміну ваги, або змісту певних критеріїв, зміну значень їх пріоритетів, але принципово, запропонований підхід до планування роботи підприємства залишатиметься незмінним.

Наведене демонструє універсальність запропонованого підходу до планування розкладу та його можливість задовольнити вимогам авіаперевізників принципово різних масштабів.

У роботі дані рекомендації з побудови відповідних схем програмного забезпечення автоматизованої системи планування.

По-перше, повинна передбачатись його гнучкість у відношенні до можливого майбутнього перепрограмування під нові потреби, критерії та пріоритети, по-друге, його структура повинна мати модульну архітектуру для забезпечення зручності внесення змін в окремі частини без порушення працездатності решти системи.

Ключові слова: теорія планування; багатокритеріальна оптимізація; пріоритети; оптимальний графік.

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The article deals with the analysis of methods for constructing a production schedule based on the theory of planning. It is shown that the most effective step in this process is to optimise the airline's activity at all levels - economic, technical, informational, and others. As optimisation of scheduling is of crucial importance in the process of organizing effective airline operations, the possibilities of using this theory in creating optimal graphics for medium and large organizations are considered.

The problem of optimisation of planning in a one-stage system with a single drive and a set of N services is considered. Selected and comparatively the most appropriate approaches to effective construction of optimal schedule. In order to streamline the criteria for optimality of the schedule to ensure the convenience of description, storage and program implementation, the conditional division of criteria into categories is proposed.

Each of the geographical, technical or transit criteria is mathematically described by the corresponding value of the priority. The paper proposes a method of prioritising criteria for different categories.

The method is based on the theoretical basis for the of the Saati analytics hierarchy process, modified for this specific problem.

From the mathematical and logical point of view, this will mean weight changes, or the content of certain criteria, changes in the values of their priorities, but in principle, the proposed approach to enterprise planning will remain unchanged. The presented demonstrates the versatility of the proposed approach to scheduling and its ability to meet the requirements of carriers of fundamentally different scales.

The paper gives recommendations on the construction of appropriate software schemes for an automated planning system. Firstly, its flexibility with regard to possible future reprogramming for its new needs, criteria and priorities must be envisaged, and secondly, its structure should have a modular architecture to ensure the convenience of making changes to individual parts without disrupting the rest of the system.

Keywords: scheduling theory; multi-criteria optimisation; priorities; optimal schedule.

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ОПТИМИЗАЦИЯ РАСПИСАНИЯ С ПРОТИВОРЕЧИВЫМИ КРИТЕРИЯМИ В ФУНКЦИЯХ

В статье рассмотрен анализ методов составления расписания производства, основанных на теории планирования.

Показано, что наиболее эффективным шагом в этом процессе является оптимизация деятельности авиапредприятия на всех уровнях - экономическом, техническом, информационном и др. Поскольку оптимизация планирования расписания занимает принципиально важное место в процессе организации эффективной деятельности авиакомпании, рассмотрены возможности использования этой теории при создании оптимального графика для средних и крупных организаций. Рассмотрена задача оптимизации планирования в одностадийной системе с единственным накопителем и набором N сервисов. С целью упорядочения критериев оптимальности расписания для обеспечения удобства описания, хранения и программного воплощения, предложено условное разделение критериев на географические, технические или транзитные категории с описанием соответствующего значения приоритета. Предложен метод приоритизации критериев по различным категориям, основанный на теоретическом фундаменте анализа иерархий Саати, модифицированном для данной конкретной задачи.

Установлено, что с изменениями ситуации на рынке производства, логистики, нормативно-правового и экономического обеспечения по-разному изменяются содержание и относительная важность самих критериев. С математической и логической точки зрения это будет означать изменение веса, или содержания определенных критериев, изменение значений их приоритетов, но принципиально, предложенный подход к планированию работы предприятия будет оставаться неизменным. Приведенное демонстрирует универсальность предложенного подхода к планированию расписания и его возможность удовлетворить требованиям авиаперевозчиков принципиально разных масштабов.

В работе даны рекомендации по построению соответствующих схем программного обеспечения автоматизированной системы планирования. Во-первых, должна предусматриваться его гибкость в отношении возможного будущего перепрограммирования под новые потребности, критерии и приоритеты, во-вторых, его структура должна иметь модульную архитектуру для обеспечения удобства внесении изменений в отдельные части без нарушения работоспособности остальных системы.

Ключевые слова: теория планирования; многокритериальная оптимизация; приоритеты; оптимальный график.

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