Information Visualization in Project Management and Scheduling

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Summary

Previous research in project scheduling has been primarily focusing on providing efficient solution procedures in a deterministic scheduling environment. In reality, however, project manager is challenged by the conflict between the dynamic and evolving nature of project information. In addition, the amount of data volume and complicated relationships among constraints make the understanding of scheduling situation difficult. Thus managers find it hard to take correct actions dealing with constantly changing constraints. In this paper, we present a research effort that experiments with allowing human schedulers to work with visualized schedules of large projects. Information visualization is used as a strategy to visually represent large data volume and their interrelationships from human problem-solving perspective. A system SWAV is outlined to support managers in making scheduling decisions under uncertainty environments. This paper describes the research problem and proposes a framework for information visualization in resource constrained project management and scheduling.

Keywords: information visualization, project scheduling, heuristic decision-making

1 The need for information visualization in project management

The vast amount and the dynamic nature of information available in project management and scheduling make the management of information critical. High complexity, constant change and uncertainty often characterize scheduling in practice. New orders flow in continually, while the promised resources may suddenly become unavailable. Resource constraints complicate the scheduling process, which is further exacerbated by the possibility that not all constraints are accurately predicted. For example, the duration of an activity may change due to a number of factors, such as the shortage of a supply in the work force, or a change in weather conditions. Resource requirements may change due to unanticipated breakdown of equipment or in a delay of delivery of raw materials. In short, the scheduling problem is a dynamic problem where continuity and reactivity must be maintained.

Resource-Constrained Project Scheduling Problems (RCPSP) are widely encountered in practice, in situations ranging from architectural construction to software project management and research and development. The problem is concerned with the scheduling of a project consisting of a number of activities that are linked together by precedence relations and multiple resource restrictions. When cash flows exist in the form of expenses for initiating activities and payments for completed work, the development of project schedules that maximize the net present value (NPV) of the project is of considerable practical importance [Bey et al. 1981]. This is a difficult combinatorial optimization problem, which precludes the development of optimal schedules [Garey and Johnson 79]. In particular, as the size of project increases, or as parameters such as duration and resource requirements of the project change, it is even harder to generate good schedules in a reasonable time. Many heuristics have been proposed in the literature to solve the resource-constrained project scheduling problem with cash flows [Davis and Patterson 75, Padman and Zhu 96, Russell 86]. These heuristics have been extensively tested on projects varying in size, complexity, level of resource-constrainedness, pattern of cash flows, among other parameters.

Previous work has been primarily focusing on proposing efficient solution procedures in a predictive scheduling environment. In reality, however, project managers are expected to face an increasing number of changing deadlines, schedule conflicts and resource allocation problems. In other words, managers may need to make adjustments regarding final solutions to the resource-constrained project scheduling problems. The massiveness of data and relationships overwhelms managers and may affect their abilities to develop better solutions. Given suggested solutions from different heuristic algorithms, managers have to understand the relationships among all the variables involved, such as precedence relationships, resource limitations, cash flow patterns, etc. Based on their understanding of the scheduling situation, managers may take some actions on adjusting schedules in order to achieve better results.

People are visual creatures. Most people, if not all, perform better when things are pictorially associated. A potential solution to the above mentioned situation is to shift a portion of individual cognitive load to their perceptual system by using computer generated information visualizations. Instead of using their cognitive powers to figure things out, managers can perceive visually what they need to perceive about the nature of all the data involved. The information visualization system should allow managers to understand the scheduling situation so that they can react within a short period of time when input conditions change. Thus, it can help managers make difficult decisions in such unstructured environments.

The purpose of this project is to address the potential of developing a visualization system to support project managers in making hard scheduling decisions in a dynamic environment. It focuses on building information visualizations of non-geometric data that are massive in both volume and dimensions to help managers to achieve data comprehension and eventually to improve their problem-solving performance. The research explores the feasibility and special concerns of visualizations for decision-making support in project scheduling and planning. Based on human problem-solving process model, we designed an intelligent project scheduling system called SWAV (Scheduling With A Vision). It aims to capture the multi-dimensional nature of the problems in easy-to-understand visual representations, and is intended to improve the performance of managers' problem-solving process. The system allows project managers to explore various alternatives, to ask what-if questions, to deal with constantly changing business environments, and to make decisions in situations that arise unexpectedly.

In the next section, we briefly describe the resource constrained project scheduling_problem with cash flows (RCPSPCF) with an illustrative example, which is followed by the motivations of using an information visualization approach in Section 3. In Section 4, we discuss a general visualization framework for project scheduling management. Some preliminary visual representations are discussed in Section 5. Finally, we conclude our work and discuss some directions for future research.

2 Project Scheduling with Resource Constraints and Cash flows

In general, a large project can be decomposed into many smaller activities. Each activity has an estimated duration, requirements on resources, and possibly associated cash flows. The resource constrained project-scheduling problem with cash flows addresses the scheduling of a number of activities subject to constraints on precedence requirements and resource limitations. A series of cash flows occur over the duration of the project in the form of cash outflows for project expenditures and cash inflows as payments for completed activities.

Figure 1 depicts an example project network. This is an activity-on-node representation. Each node represents an activity and the directed arcs represent the precedence relationships among activities. Each activity i (i = 1,…, m) has a fixed duration di, resource requirements (ri1, …,rik) of k types (in this example k=3), and cash flows Fo and Fi in representing expenses and payments. The label associated with activity C, for example, has three components: cash flows [-16, 41], resource requirements (6,1,4) and duration 2. Analogous labels are associated with other activities. The first cash flow associated with an activity is non-positive, represents the cost of the activity, and its incurred at the activity's start time; the second cash flow is non-negative, represents the payment for completing the activity, and is obtained at the activity's completion time. In this study, we assume that resources are renewable ones. Duration, expense and payment associated with each activity are known. The expense occurs at the beginning of the activity, while payment is made at the completion of the activity. The model can be easily extended in the situations when cash flows are associated with a set of activities.

Given such project networks and predefined discount rate for cash flows, the problem with net present value objective can be formulated as a mixed integer-programming model. This is a difficult NP-complete problem. Thus, heuristics have been proposed and tested extensively in this area [Russell 86, Padman 90, Baroum & Patterson 93]. Study has been conducted to explore project structure in order to discover the underlying relationship between some of the critical project parameters and heuristic performance [Patterson 76, Zhu and Padman 95]. Local search method has also been used and was found to have tremendous success in solving the problem [Zhu & Padman 96]. In addition, a problem space computational model is proposed to integrates multiple sources of knowledge (such as optimization models, heuristic procedures, and heuristic selection techniques) to support scheduling process [Padman and Zhu 95]. The above discussion is mostly limited to the deterministic nature of the problem. In reality, however, those parameters such as activity duration, resources, and cash flows may change in response to external unexpected occurrence or constraints. Under certain circumstances, resources (including raw materials, machines, human resources as well as capital budgeting) originally promised may not be readily available. These may influence the duration – the time to complete certain activities. The capital budgeting constraints may also have a direct impact on the cash flows. In the event when such uncertainties occur, the initial solution obtained from algorithms or heuristics may not be a good one or even feasible. Project managers have to be able to react to such uncertainties in a timely fashion by making proper adjustments on the current schedule. Without an intelligent tool to assist in such complex decision making process, project managers will easily be at a loss and even fail in managing such risks. This is a critical problem and presents a good opportunity for information visualization techniques to play important roles.

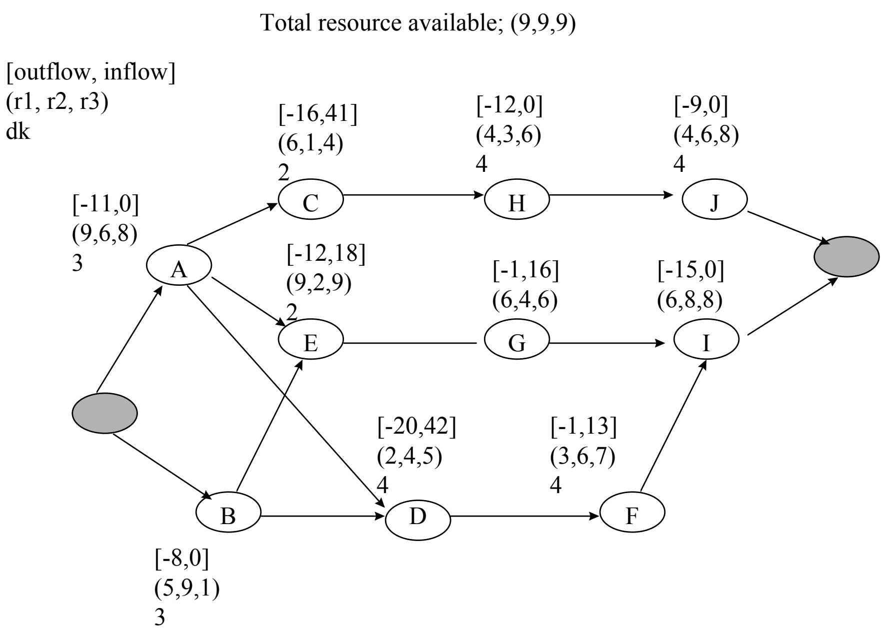


Figure 1 : Example Project Network

3 Information Visualization

Recent advances in information technology have enabled the development of sophisticated graphical user interfaces for the visualization of large quantities of data [McCormick 87, Rosenblum 92, Reuter 90] that are either gathered from the real world and analyzed by a computer or produced through computer simulations. Visualization means using computer-generated graphics to help people understand and clarify visually the relationships inherent in data [Rosenblum 92]. Research in scientific visualization has enabled many applications that involved the visualization of systems that are naturally represented as two- or three-dimensional objects. Examples can be found in visualizing biological molecules, medical imaging, tracking and imaging elementary particles, among others.

Recently, efforts have been made to visualize large volume non-spatial data that do not have inherent geometry to lead to computer-generated representations. This type of visualization is thus named information visualization. Special challenges for information visualization include creating visual representations that utilize human visual perceptual capability and enhance human information comprehension. Among few business applications of information visualization are treemaps [Shneiderman 92] and VIZ_planner [Zhang 96]. TreeMaps can be used for visualizing huge amounts of hierarchical and categorical information such as file directories, budgets, sales data, and organizational structure data. Data items involved can be in thousands even millions. Zhang takes a different approach by concentrating on irregular structures among data and human problem-solving process. VIZ_planner can help production planners to develop superior manufacturing production plans that have hundreds of products, thousands of parts, and many other factors. Resource-constrained project scheduling and management is another area that information visualization can play an important role in improving schedulers problem-solving performance. It is, however, far from obvious on how to represent the many important factors with complicated relationships.

4 Scheduling With A Vision (SWAV)

A human scheduler, when faced with a scheduling problem, needs to go through several general stages of the human problem solving process, as identified by Simon and Newell [Simon 76, Newell & Simon 72]. This process includes identifying the problem, generating alternatives, and evaluating alternatives.

Among the three tasks in Simon and Newell's model, the most difficult one is identifying problems. When thousands of activities and hundreds of resources are involved in a project, schedulers need to have an overall understanding of the entire project in terms of potential bottlenecks. Each node in Figure 1 has a description about resources requirements, duration for the activity, and cash flow information. The project network also shows the precedence relationships. When a project network is small, each node is visible and thus the project is somehow manageable. When the network becomes real large, for example, with hundreds or even thousands of nodes (activities), the situation is complex and it is almost impossible for the scheduler to trace each node, a subset of network, or the entire network. The challenge is how to represent an overall view of the entire network so that without looking at the details at each node, managers are still able to tell the potential bottlenecks or conflicts. SWAV is designed to help project managers to identify such bottlenecks or conflicts during the entire scheduling period. It should also provide intermediate levels of understanding about the resource availability/shortfall situations.

When a bottleneck is identified, a scheduler may use his or her domain knowledge to develop alternatives and take certain actions to reduce or solve the problem. Among the many possible directions for taking actions, which way to go remains a question. Meanwhile, there might be some directions/actions that the scheduler could not see due to the complexity of the relationships and large volume of data. SWAV provides some evidences that can point out potential directions. It should keep the managers aware of how well the action can improve or worsen the situation.

For each alternative schedule, there is a NPV based on the objective function introduced earlier. Using NPV or some other criteria can do evaluation of an alternative. SWAV will allow the manager to do what-if analysis in the decision support contexts. With the scheduling objectives in their minds, managers can decide which alternative should be the final solution to the resource-constrained scheduling problem.

Figure 2 presents the major components of SWAV system. There are two principle processors and several agents (not shown in Figure 2) in SWAV system. A heuristic engine is an underlying computational processor for generating regular schedules. It may include any heuristic algorithm or a combination of heuristics. The input data for the heuristic engine include raw data (such as activity duration, resource availability, resource usage, cash outflows and inflows, etc.), as well as objective function and constraints. These data are assumed to be given to reflect the moment of the environment when the scheduling process starts. The results from this heuristic engine are regular schedules. Info_visualizer is another processor that represents the regular schedules into visual forms so that important factors and relationships are depicted. Info_visualizer also provides the user interface with the help of several agents so that human schedulers can work directly with visual schedules. Besides the given input for the heuristic engine, there is another type of input called uncertain events from external constraints. Uncertain events are about the changing information that happens during a time period. Usually this type of input affects the entire scheduling, thus is an input to the SWAV system. In practice or reality, this type of input happens most of the time. Current existing project scheduling methods are limited to handle this situation.

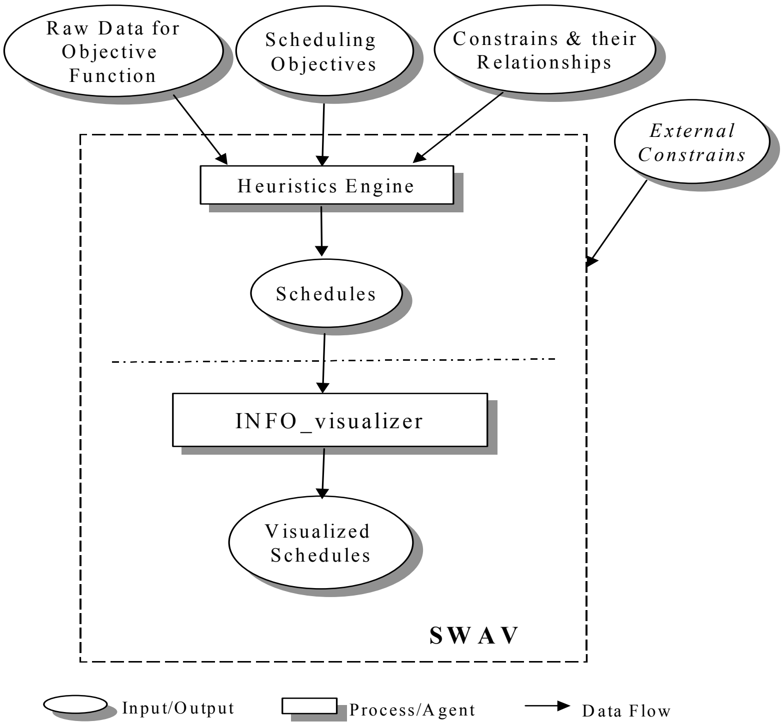


Figure 2 : SWAV System Components

5 Examples of Visual Representations

The above section describes the general framework of our proposed system. The detailed procedure of applying such framework to RCPSP is omitted due to the space constraint. In this section, we present some preliminary design of visual representations SWAV can provide to human schedulers. Info_visualizer takes a schedule from the heuristic engine and presents the schedule in visual forms. We use the example in Figure 1 to illustrate some major points in the visual displays. Since some project management charts such as Gantt and PERT charts are very popular and well used in the field, we incorporate them into the SWAV system. Next we will show visual representations that can indicate information those charts do not provide.

Figure 3 depicts the status of critical factors such as cash inflows, outflows, and utilization of three resources during the entire project life cycle (28 duration units). A human scheduler usually needs to consider all these types of information in order to evaluate or generate a schedule. These factors are represented using standardized values thus comparisons are possible. Color coding is consistent in the system to represent different factors. Basically, the scheduler uses Figure 3 to identify some global patterns that are hidden in the data. For example, how do cash flows change over time with resources' utilization change at the time? Hopefully some patterns can be used to guide the scheduler to take some actions that have influence on the entire project, not just neighborhood or a small part of it. These global patterns provide directions on improving the schedule at a high level. This means that the scheduler does not need to look at each activity in order to have a big picture about the status of the current schedule in terms of the critical factors.

One interesting observation from Figure 3 is that resource 3 seems to be the bottleneck among three resources. The current schedule does not seem to be adjustable since resource 3 is utilized most of the time. Resources 1 and 2 together are moderately utilized during the middle stage of the life cycle. In this particular example, no special pattern or relationship between changes of cash flows and changes of resource utilization can be identified.

A further analysis of any resource is possible by zooming in Figure 3 on the resource. For example, Figure 4 illustrates the resource utilization profile for resource 1 (r1). As we can see from Figure 4, there is no over-utilization of resource 1 from this schedule. The peak demand for this resource occurs in time period 1-3 and 23-25 when the total 9 units of resource 1 are completed consumed. Resource 1 reaches the lowest demand in the time period 9-11. In the event when unexpected demand (or a shortage) occurs, the parts we worry the most are those time periods when resource is fully unutilized. Furthermore, by reviewing the integrated representation and resource profiles for all the resource types, we are able to get certain hints on better utilizing resources and resource conflicts resolution. In Figure 4, we used same orientation (from origin down to the bottom of the chart) of resource utilization as that in Figure 3 to keep them consistent.

Zooming in can also apply to cash flows. Figure 5 shows both in flows and out flows with the same scale. An alternative representation is to consider out flows as negative flows and in flows as possible flows. Thus two types can be in one chart.

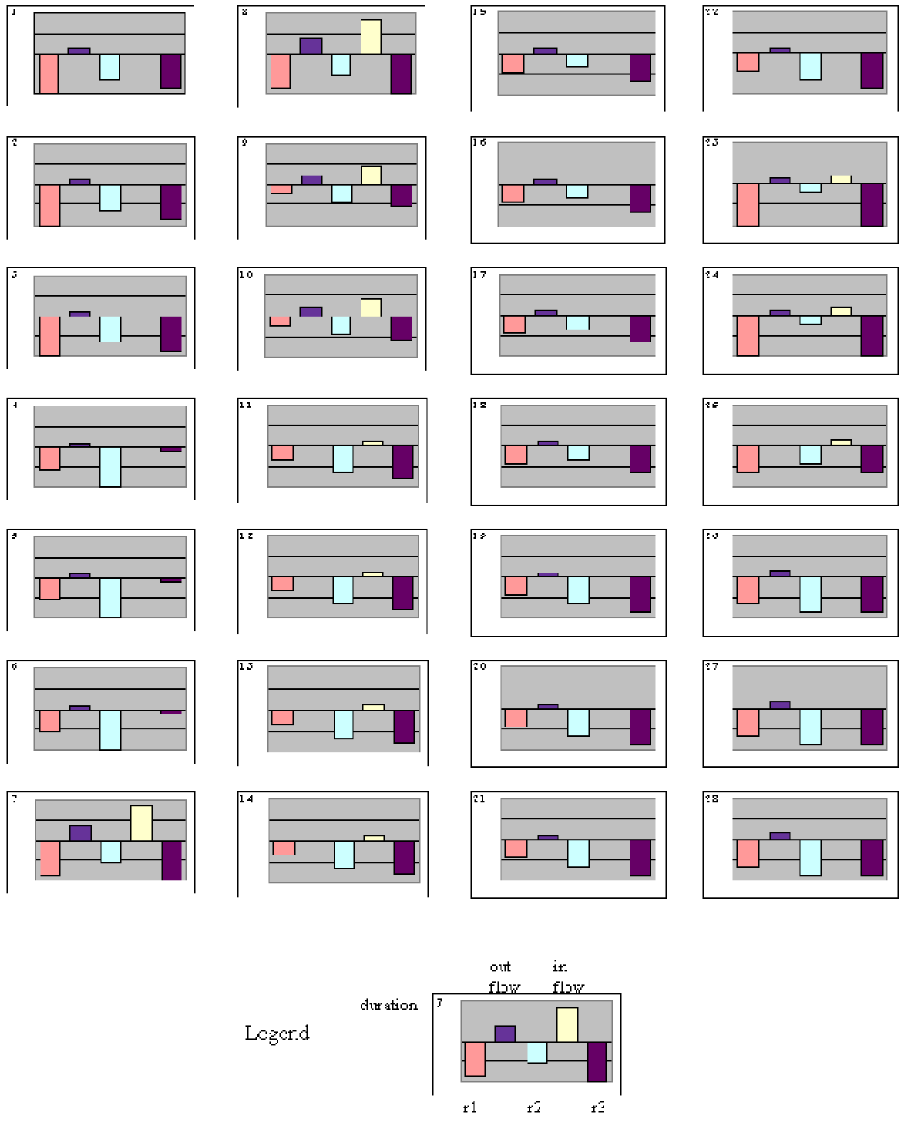


Figure 3 : Visual Representation of a Schedule for the Example Project

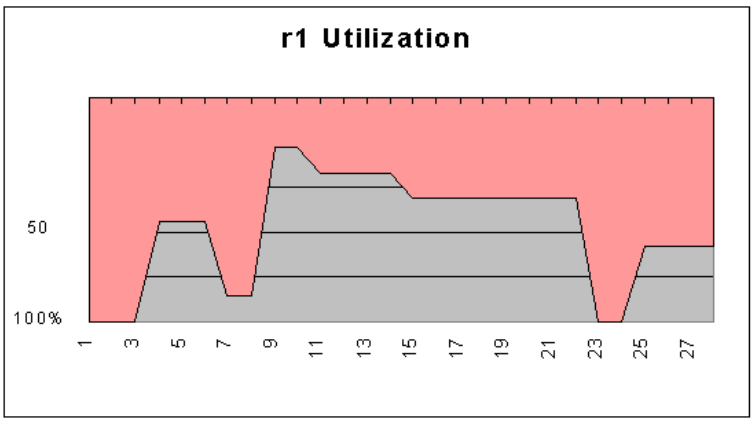
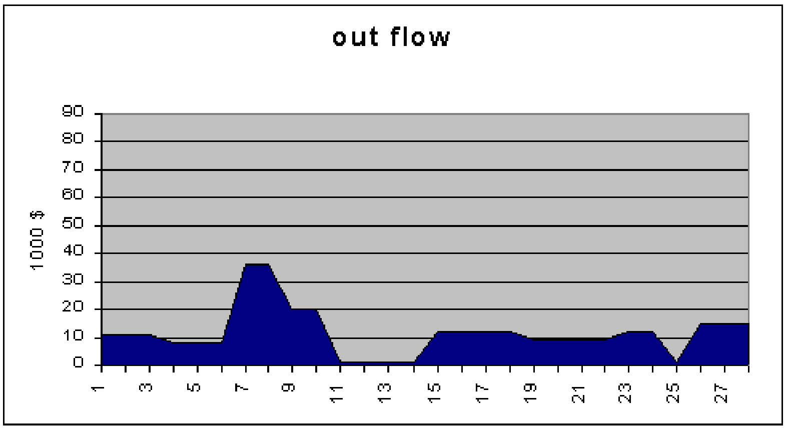


Figure 4 : Resource Utilization Profile Over Time for Resource 1



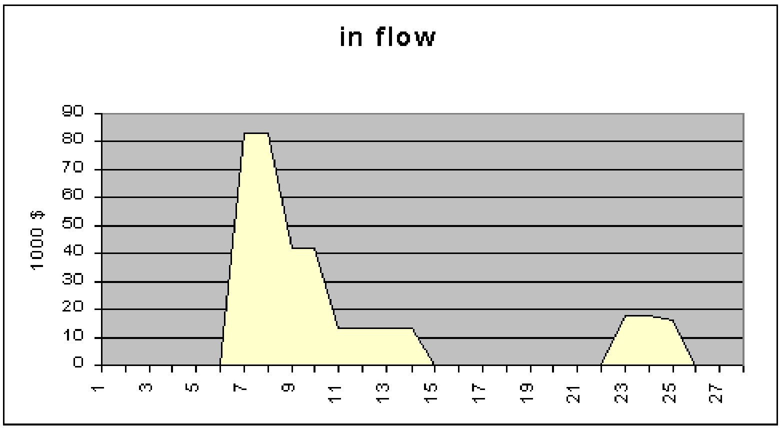


Figure 5 : Cash flow profile over time

6 Conclusion

Information visualization is a powerful technique with tremendous potential in supporting complex decision-making. However, still in its infant stage, information visualization requires research exploration on research methodology, special techniques, and more applications and system evaluations. The current research adds value to this area and is expected to increase its value in the real world for project managers dealing with uncertainty in resource-constrained scheduling and management.

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