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ANALYZING AND RE-ENGINEERING BUSINESS PROCESSES USING SIMULATION

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ABSTRACT

Increasingly, companies around the world are re-engineering their core business processes to be more profitable and to improve customer satisfaction. Modeling and analysis are two critical steps in any process redesign effort. In this paper, we discuss the need for simulation tools that can be used effectively to model, document, and analyze business processes. We also present the design of such a hierarchical simulation tool called BPMAT and discuss its implementation.

1 INTRODUCTION

Business Process Re-engineering (BPR) is a recent addition to the suite of approaches that business managers can use to improve the performance of their business. Over the last two years many corporations have engaged in re-engineering efforts. In spite of uncertain results (Hall, Rosenthal, and Wade 1993), the success stories have resulted in new BPR projects being initiated regularly.

While the merits and innovative aspects of BPR are open to debate (Vitiello 1993), BPR provides opportunities for management science and operations research professionals to use their skills and tools in helping shape decisions that have great implications for businesses (Cypress 1994). In exchange, these professionals can enrich BPR by contributing scientific analysis to complement the qualitative thinking currently used in the field.

Investigating the business process under study and creating new process designs requires strong modeling skills and good tools. There are various modeling approaches that can be used. Van Ackere, Larsen, and Morecroft (1993) argue that since BPR has its roots in systems engineering (where a system may be a business system, a manufacturing system, a social system, etc.), the systems thinking approach is quite appropriate for BPR modeling. Systems Engineering offers many modeling and analysis tools such as simulation, decision theory, queueing theory, optimization, utility theory, and others. The authors emphasize simulation, they contend that recent advances have made simulation technology more accessible for use in BPR. Ardhaldjian and Fahner (1994) go further when they show how simulation in BPR can be used not only for modeling the "As is" and "To be" processes but also for marketing, communication, educational, and benchmarking purposes.

Our experience at IBM suggests that simulation can play an important role in the modeling and analysis activities that take place in a Business Process Re-engineering effort. When used appropriately, simulation has been able to provide quantitative estimates of the impact that a process redesign is likely to have on key performance measures. In sharp contrast to other modeling methods, such as optimization models or systems differential equations, simulation is well suited to handle the stochastic and time-varying nature of processes as well as the non-linear interactions between process elements.

To encourage a more widespread use of simulation by IBM analysts and consultants, we have developed a Business Process Modeling and Analysis Tool (BPMAT) that has an advanced graphical user interface and has strong simulation capabilities. BPMAT was designed and implemented according to requirements identified through formal surveys of BPR field practitioners, pilots, literature review, and the evaluation of existing simulation tools. It provides, in an integrated environment, the means for documenting a process and capturing in a hierarchical model the characteristics that are important for a process redesign. Through simulation, users can evaluate the effect that re-engineering designs may have on performance measures. The tool may also be used to visually present process design and simulation results leading to improved communication between participants in a re-engineering effort. Finally, BPMAT provides mechanisms for managing and sharing the intellectual capital that gets created in re-engineering engagements.

This paper is organized as follows. In section 2 we review existing literature on BPR and simulation. In section 3 we discuss requirements that are specific to BPR simulation tools. Section 4 contains an overview of BPMAT. In section 5 we provide details about the main modeling concepts in BPMAT. In section 6, we discuss various usage scenarios of the tool. Finally, in section 7 we present our conclusions and plans for future work.

2 BACKGROUND

Re-engineering is a highly public field, with people expressing conflicting views. Here we attempt to present those views without necessarily endorsing or rejecting them. In fact, the authors of this paper don't hold a single collective opinion about BPR, its merits, and limitations.

Michael Hammer's work (Hammer 1990 and Hammer and Champy 1993) provides the most frequently quoted definition of business process. Most authors seem to follow his lead in defining business processes as a set of tasks typically crossing organizational boundaries which deliver something of value to an internal or external customer. The term "re-engineering" captures the radical redesign of these processes.

Hammer and others assert that historically the processes in a typical organization were never engineered at all, let alone with the broad business goals in mind. Rather they evolved over time from temporary procedures and quick fixes. Hammer argues that the typical organization evolved in an entirely different business environment than that in which we now compete. As a result, today's typical business processes contain much unnecessary content, make the leaps across organizational boundaries poorly, and actually impede optimal business performance. Thus, radical change is needed. Small incremental improvements simply won't do.

Reports of business process re-engineering work indicate that it is proceeding with vigor in spite of unsettlingly low success rates, mostly less than expected results, and some spectacular failures (Caldwell 1994, Hall Rosenthal and Wade 1993, Arend 1993). Seemingly, the trend to reengineer has impetus from the publicized successes, our own corporate cultures (Vitiello 1993), but the fact is that competitive pressures are forcing companies to change. Re-engineering, by Hammer's definition, is a good way to go about it, in spite of uncertain results.

Hammer's (1990) definition emphasizes radical change through application of information technology. Davenport and Short (1990) also stress the role of information technology. Information technology has a dual role in the transformation of business processes (Van Ackere, Larsen, Morecroft, 1993). As originally highlighted by Hammer, it enables new levels of productivity, new kinds of organizational structure and deployment, and new kinds of products and services. Davenport and Short (1990) suggest a recursive relationship between this role for information technology and business process redesign. New technologies enable and therefore cause redesigns of business processes while, in general, process redesign should be done with the intent of exploiting technology. In the second role, information technology can help in the mechanics of the transformation itself in modeling the options and assessing the changes with the greatest impact. It is this second role that captures the essence of our work.

Van Ackere, Larsen, Morecroft (1993) argue that simple process maps do not typically provide sufficient understanding of the process to know what to change although many teams start this way. Van der Aalst (1992) suggests that the intended analysis dictates the type of modeling that is done. The goals of a re-engineering effort are most often framed as quantified business improvement measures. The process map helps the team understand the problem framework, but to aid a team in knowing what to change, the process map must be backed with numerical analysis.

If the process does not contain significant randomness in either its environment or its internal features, basic mathematical analytical techniques may be indicated. Such cases can benefit significantly from optimization employing linear programming, mixed integer programming, goal programming, and other operations research techniques. Simulation, however, is typically employed in situations where the random content does matter and cannot be modeled by other analytical techniques. Cheng (1992) views simulation as a tool of last resort to be employed only when other methods are ruled out. He cites the high computational cost and the time and effort required to build models as disadvantages of the simulation approach. On the other hand, Swain (1993) suggests that the ease of model building and cost economies in computing make simulation the tool of choice for modeling complex systems and validating analytical models before proceeding to optimization.

Van der Aalst (1993) suggests that the complexity and analytical detail are essential to sound analysis. Yet, excessive complexity and detail can impede human understanding of the process. Van der Aalst recommends a library of reusable, domain specific building blocks which themselves may be quite detailed but can be used as black boxes. We favor Zeigler's (1987) earlier work as a more complete treatment of the issue. Processes can be hierarchically decomposed to the level of detail necessary to suit the analysis and the needed human understanding. And such abstractions can be organized into domain specific libraries for reuse.

Arend (1993) asserts the value of models and simulation in building consensus and generating new ideas within a re-engineering team referencing IDEF0 as a valuable communications vehicle. Hall, Rosenthal, and Wade (1993) list overlooking communications as one of four most damaging practices in re-engineering work. Hammer says that communications has two purposes in the context of re-engineering: to make a compelling case for change and to create a vision of what the company is to be (Karlgaard 1993). We see these messages of change and vision as most suitably coming from the office of the CEO as leader and lead designer of the organization (Keough and Doman 1992).

3 REQUIREMENTS FOR A BPR MODELING TOOL

In 1992, we conducted a detailed survey of more than fifty analysts and consultants who were directly involved in various business process re-engineering efforts. The goal of the survey was to identify the key features required in a business process modeling and analysis tool. We also reviewed existing literature on business process and enterprise modeling. From this effort emerged an early design for a hierarchical business process modeling and simulation tool.

Soon after, we had the opportunity to use that design to model and analyze the supply chain of an IBM business. We developed a simulation program that had no graphical user interface and used it to model the demand planning, parts procurement, production planning, manufacturing, warehousing, distribution, and order fulfillment processes. The interactions between these processes were carefully modeled. The results of this work played a major role in shaping the strategy of that IBM business. Since then we have used the program in various other simulation studies to help IBM reengineer its key business processes in this specific domain (An et al. 1994).

From this experience, we have developed a set of requirements that we believe should be met by tools used for modeling and simulating business processes. These requirements can be organized into five categories: process documentation, process redesign, performance measurements, communication, and institutional learning.

One of the most common activities that consultants and analysts engage in at the outset of a BPR effort is to document the existing business processes. This documentation can be either in the form of descriptive text or as process maps. It becomes the basis for a shared understanding of the documented processes. Therefore any BPR modeling tool must have documentation capabilities otherwise it creates redundant efforts.

Since we expect business process modeling tools to be used in re-engineering studies, it is important that they have the ability to capture characteristics that are relevant to process redesign in a model. First, one should be able to represent structural changes in the process such as eliminating non value-add activities, minimizing rework, consolidating process steps, reducing the time it takes to perform some activities, etc. Second, it is important that policy changes akin to routing jobs in the process and regulating the output of an activity as a function of its input can be modeled. Next, because resource allocation issues are very important in a process model, a BPR simulation tool should provide ways to model resource requirements for activities, processing rates for resources, number and mix of resources, resource capacity, and resource availability schedules.

One of the main benefits of simulation is that statistical estimates of various performance measures can be easily obtained. We have found that the following measurements are considered to be crucial across many BPR efforts: cost, cycle time, work-in-process, serviceability, resource utilization, and quality. We therefore believe that good BPR simulation tools should provide reliable quantitative estimates of the above measurements.

While modeling a process is a critical step in BPR, presenting the model to others can be often just as important in insuring the success of a re-engineering effort. First, if a graphical process map is used to gain agreement from various people involved in a re-engineering effort, it is more likely that a common view of the existing process and of the proposed process designs emerges. Thus the ability to generate and print such a map should be a feature in BPR modeling tools. In addition, simulation tools that generate graphical charts to summarize the statistical results of simulation output provide the analyst with an effective means of presenting results to others. Tools that provide histograms, bar charts, pie charts, trace charts, etc., become valuable re-engineering aids.

Consultants and analysts are often very concerned about managing the intellectual capital that is gained over time. This particularly holds true in the BPR arena. In effect, business processes that deliver equivalent products (or services) tend to share many components across various enterprises. For example, many of the same principles and designs form the basis of the order fulfillment process that exists in various companies even if those companies come from dissimilar industries. The consultant or analyst who leverages the knowledge gained in one engagement and uses it in subsequent studies makes better use of time and resources. It is therefore essential that a BPR modeling tool provides the means for capturing intellectual capital in the form of process models and allow the analyst to share and merge process models within a consulting engagement or across engagements.

We also believe that a good BPR simulation tool should not only provide the above requirements but it should also integrate them in a coherent way. Finally, such a tool should be easy to use and should have a graphical user interface designed for this specific goal. It is with these requirements in mind that we have conducted our research and development of BPMAT.

4 OVERVIEW OF THE BPMAT

BPMAT is the product of a joint development effort between the IBM T. J. Watson Research Center and CACI Products Company. It was developed using MODSIM II, an object-oriented simulation language sold by CACI. SIMOBJECT, CACI's object-oriented framework, provided an advanced starting point for building the tool. BPMAT runs on the Unix, Windows, and OS/2 operating systems. The main graphical editor is shown in Figure 1.

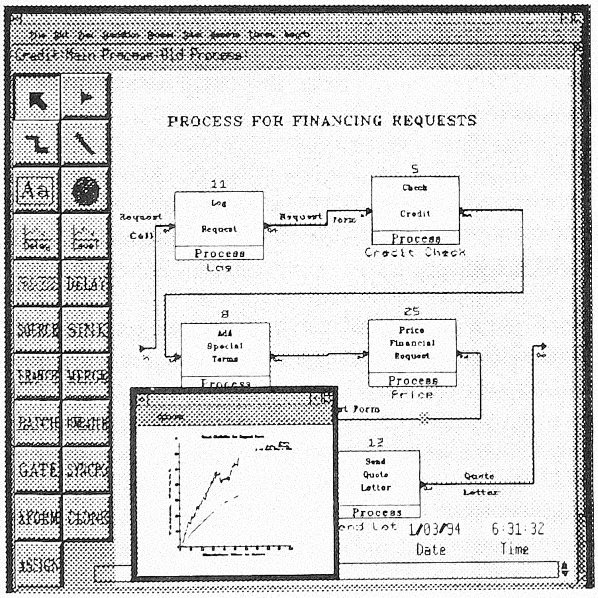

Figure 1: BPMAT's Main Graphical Editor

Notwithstanding the SIMOBJECT libraries, BPMAT consists of approximately 300 classes and 50,000 lines of code. As shown in Figure 2, the software is organized in four major levels of hierarchy. The first two levels, called MetaLib and SimLib, constitute the SIMOBJECT class libraries. MetaLib contains the classes that manage the graphical user interface including animation, while SimLib contains the classes that implement simulation, input and output interface, and the library management capabilities. The last two levels, are SimDemo and BPMAT. SimDemo contains the drivers necessary for the implementation of the application. BPMAT, which is derived from all of the above libraries, contains the objects specific to the BPMAT application, such as Activities, Resources, and Reports. The Integrated Development Environment (IDE) includes a compiler, an object browser, and a graphical user interface builder.

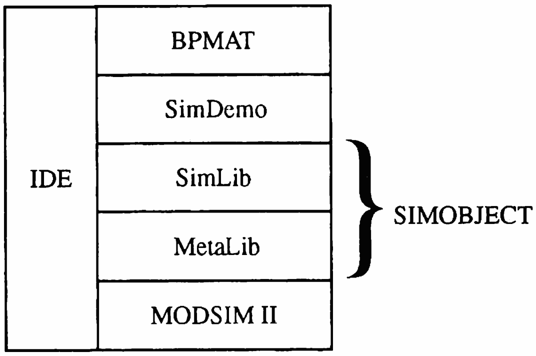

Figure 2: BPMAT Software Architecture

4.1 Modeling Processes with BPMAT

The three main concepts a user of BPMAT manipulates to create a business process model are Processes, Resources, and Tokens. Figure 3 illustrates the relationship between these concepts. A process represents behavior or actions and may require some amount of time to be performed. A resource is used to model the objects that can perform a task or are used in some process. Finally, tokens are elements that flow through a process and get transformed. For example, parts (tokens) may flow into a process that uses people and equipment (resources) to make products (tokens). Section 5 contains a more detailed description of these three concepts.

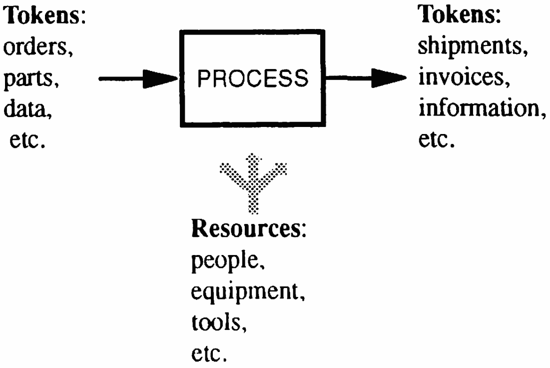

Figure 3: BPMAT Modeling Concepts

In BPMAT, a business process model is created by graphically selecting activities and processes from the palette bar, customizing their behavior through parameters presented in a dialog box, linking them together with input/output arcs, and specifying the tokens that flow between them and the resources that are used. A business process model has two views: one is static (descriptive) while the other is dynamic (behavioral). The static view captures the sequence of activities, the flow of tokens, the resources that are used and contains a textual description that is used to understand the process. The dynamic view captures the information that is used to represent its behavior (durations, release rates, usage rate). Simulation is used to execute the business process model and collect measurements that indicate its performance (cost, cycle time, defect rates).

4.2 BPMAT Reporting Capabilities

BPMAT's reporting functions allow the user to specify the types of reports that will be needed prior to running the simulation. BPMAT monitors only those processes, activities, tokens, and resources necessary to produce the user specified reports. BPMAT's time series reports show cycle times, token counts, and the various states of resources. They are continually updated while the simulation is running. Other reports such as the cycle time distribution, average, and peak, the token count distribution, average and total, as well as the resource capacity utilization are plotted using graphs such as histograms, bar charts, and pie charts. These reports can be selected for display by the user at the end of a simulation. In addition, data from the charts can be viewed in tabular format and saved to files for further processing.

4.3 BPMAT Libraries

Several types of libraries are available in BPMAT. They are user defined process libraries and system defined process libraries. Users have the ability to define their own libraries and populate them with customized activities, processes they have created, and processes they select from other libraries and applications. This enables a user to organize and reuse processes conveniently. System defined process libraries contain tested, domain specific processes that are developed programmatically. These processes are building blocks from which applications can be developed. For example, process building blocks relevant to such domains as manufacturing, distribution, insurance claim processing, etc., can be organized in libraries and made available to users. The Manufacturing library may contain processes such as Assemble, Transport, Warehouse, Process Order, Distribute, etc. A user is free to use them, modify them or add them to their own libraries.

5 BPMAT MODELING CONCEPTS

In this section we describe in detail our notion of processes, resources and tokens.

5.1 Processes

A key distinguishing feature of BPMAT is its hierarchical process modeling ability. This enables a user to decompose a process into as many levels of detail as required. This capability greatly enhances the ability to understand a process by facilitating the decomposition of the process into sub-processes that can be refined with more details. There are two concepts used to create process models in BPMAT. They are Process and Activity. The Process construct allows the user to create hierarchical process models. Activities are the objects at the leaf level of the process model. They are non-decomposable objects and have an associated behavior such as using a resource to perform some activity that has a duration.

A challenge in the design of BPMAT is to provide a set of Activities that can be used to compose models of a large portion of business processes. There are currently twelve Activities defined in BPMAT:

- Source generates tokens (orders, parts, etc.) at specified intervals of time during simulation.
- Sink accumulates all relevant statistics on the tokens that flow into it and then disposes of the tokens.
- Delay models the passage of time and usage of resources.
- Branch routes tokens through alternative process paths during simulation based on probability or characteristics of the arriving token.
- Batch aggregates tokens based on batching parameters.
- Unbatch unbundles a batch into the tokens which comprise it.
- Clone duplicates the arriving token and releases a user specified number of copies.
- Transform converts one type of token into another type.
- Gate stores arriving tokens and holds them until a trigger signal is received.
- Synchronize synchronizes the release of tokens when one of each type is available.
- Merge funnels tokens from many different paths through one common process.
- Assign assigns a value to a user specified attribute.

The user creates parameterized instances of activities and connects them with arcs to define processes.

5.2 Resources

The second primary modeling concept is Resource. A resource may be used to represent things like people, tools, computers, trucks, manufacturing equipment, floor space that are required to perform tasks associated with an activity. The limited availability of resources can often constraint the performance of a business process. Associated with a resource is a unit of capacity which specifies the amount of work that can be performed. For example, a gas station may have 10 pumps (capacity is ten) or a person can perform only one task at a time (capacity is one).

Many advanced functions for resources are available in BPMAT. The user has the ability to schedule planned incapacitation, or time periods during which resources are known to be unavailable. For example, if a person does not work on weekends, the resource can be scheduled to be unavailable on Saturday and Sunday. Unplanned incapacitation, e.g. random machine down times, can also be modeled. The user can also reserve resources so that only one activity can be using the resource at a given time. Finally, the user can define the set of resource combinations that can be used to perform an activity and the quantities required for each resource.

BPMAT contains two orthogonal hierarchies built upon resources: departments and workgroups. Departments represent collections of resources and departments. A resource or a department may not belong to more than one department. Departments are used to group resources in a hierarchical manner similar to that of many traditional business organizations. On the other hand, workgroups represent collections of resources, departments, and workgroups that are required to perform a task. Any given resource, department, or workgroup may take part in more than one single workgroup. Using the department and workgroup structures to arrange resources provides the user with a more realistic and versatile model of business processes.

5.3 Tokens

The third primary modeling concept is Token. Tokens are the objects that flow though the process during simulation. They represent the physical units (parts, products, etc.) and informational units (orders, signals, etc.) that trigger the behavior of activities. They can also be transformed into some other token by the work performed at the process. An order, for example may be tracked through a business process, operated upon, or trigger some behavior in a process and can have data collected on the cost and time associated with fulfilling it.

Tokens are also hierarchical. A token may contain other tokens that retain their original identity. For example, a shipping palette may contain some quantity of personal computers. The palette may travel as a single unit during transportation but will get disaggregated into its constituent parts when it reaches its final destination. A token can also have a count that signifies the number of such identical tokens that it contains. However, in this case the identity of the individual units is not kept. This feature is used to model large numbers of identical tokens where the individual elements don't need to be distinguished from one another, e.g., a truck load of oranges or a shipment of capacitors.

A user has the ability to define the tokens that are relevant to the business being modeled. Since it is impossible to envision all the attributes of these tokens, BPMAT provides user defined variables. Using this capability, a user can associate attributes with tokens and can set, branch upon, and monitor these attributes during simulation. For example, a user can define a Token called PC, and associate a user defined attribute called COST with it. It can then be used to accrue costs, to branch on its value, and its final value may be inspected at the end of simulation.

6 USING BPMAT

BPMAT is useful in three complementing, but distinct, paradigms of use: the Committee Paradigm, the Dynamic Hypothesis Paradigm, and the Numerical Paradigm.

6.1 The Committee Paradigm

Re-engineering work is often collegial in nature. That is, it often involves several people from different organizations, disciplines and even enterprises. Re-engineering work, then, can consist in large part of co-operative work often carried on in a committee room where the results of data collection efforts are presented and plans are made for the next phase of data collection or re-engineering. Because BPMAT provides a graphical representation of business processes, it can be useful in allowing simultaneous development of different parts of a model or in communication about a model. In essence the screen displaying the BPMAT model can be the blackboard for the re-engineering workgroup's meeting. BPMAT in this paradigm is essentially an information collection and storage device, where information about different parts of an organization is kept, in a way that makes it meaningful in the context of the whole business process. It may even contribute to the clarity of the discussion!

6.2 The Dynamic Hypothesis Paradigm

Once the model has been constructed and all the data has been collected and stored in the model, BPMAT can simply be run. That is, the business process is simulated, and it is possible to receive tabular and graphical information about the simulation run and its results. Through the animation feature, it may be possible simply by watching the screen during the run to form impressions about where the significant bottlenecks and gates in the process occur. This dynamic simulation capability, specially the iconic monitoring aspects can sometimes explain the puzzle of why a perfectly good business process design fails in service.

6.3 The Numerical Paradigm

Once a simulation has been run, it is possible to begin a series of numerical experiments to explore the functioning of the business process in service. This can be done in two ways:

- Parameters of the various processes can be changed and the simulation can be re-run to examine the effects, for example of different resource constraints.
- Structural variations of the model can be constructed and run. This allows exploration of different designs for the same process, and these designs can be significantly different.

6.4 Other Usage Paradigms

Although we have described three different contexts in which BPMAT can prove useful, there are many other ways in which BPMAT can be used --- as devices for storing organizational histories, as a way of comparing how different organizations can carry out the same function.

7 CONCLUSIONS

Our goal in developing BPMAT was to create an integrated software package that could be used throughout a business process re-engineering effort. This was accomplished by developing a software tool that was designed to address each aspect of the re-engineering process (see section 3) and by presenting the functionality of BPMAT in an intuitive manner through a well thought out graphical user interface.

A major benefit that BPMAT affords through its ease of use is that re-engineering practitioners can simulate the business process under investigation and obtain quantitative measurements of key business processes (cost, cycle time, resource utilization, etc.). This allows the evaluation of alternative process designs in terms of quantitative criteria and the selection of the most promising ones for implementation. In addition, the ability to create libraries of domain specific process building blocks (warehouse, transport, etc.) or of complete process applications (Supply Chain Management, etc.) accelerates the development of new models and provides a repository of knowledge captured from previous re-engineering efforts.

We currently have 50 users of BPMAT and are participating in several pilot re-engineering studies using BPMAT. Additional features are being added to BPMAT. Currently underway is the design of a form of activity-based costing (Turney 1991) that enables cost estimates to be obtained through simulation as well as statically. User defined variables will be enhanced so that they can be associated with processes and the global model as well as with tokens. In addition, these variables will be available to the user for making policy decisions and collecting statistics on objects of interest. Several new reports and ways to expedite their viewing are also being developed.

It is our belief that the integration, functionality and ease of use that BPMAT provides will enable re-engineering practitioners to evaluate many more process alternatives and select the most promising approaches based on quantitative metrics as opposed to basic intuition. BPMAT should reduce the time required to perform a reengineer engagement and assist in the discovery of novel process designs.

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