OPTIMIZEIT APC

A comprehensive solution package for advanced process control and optimization

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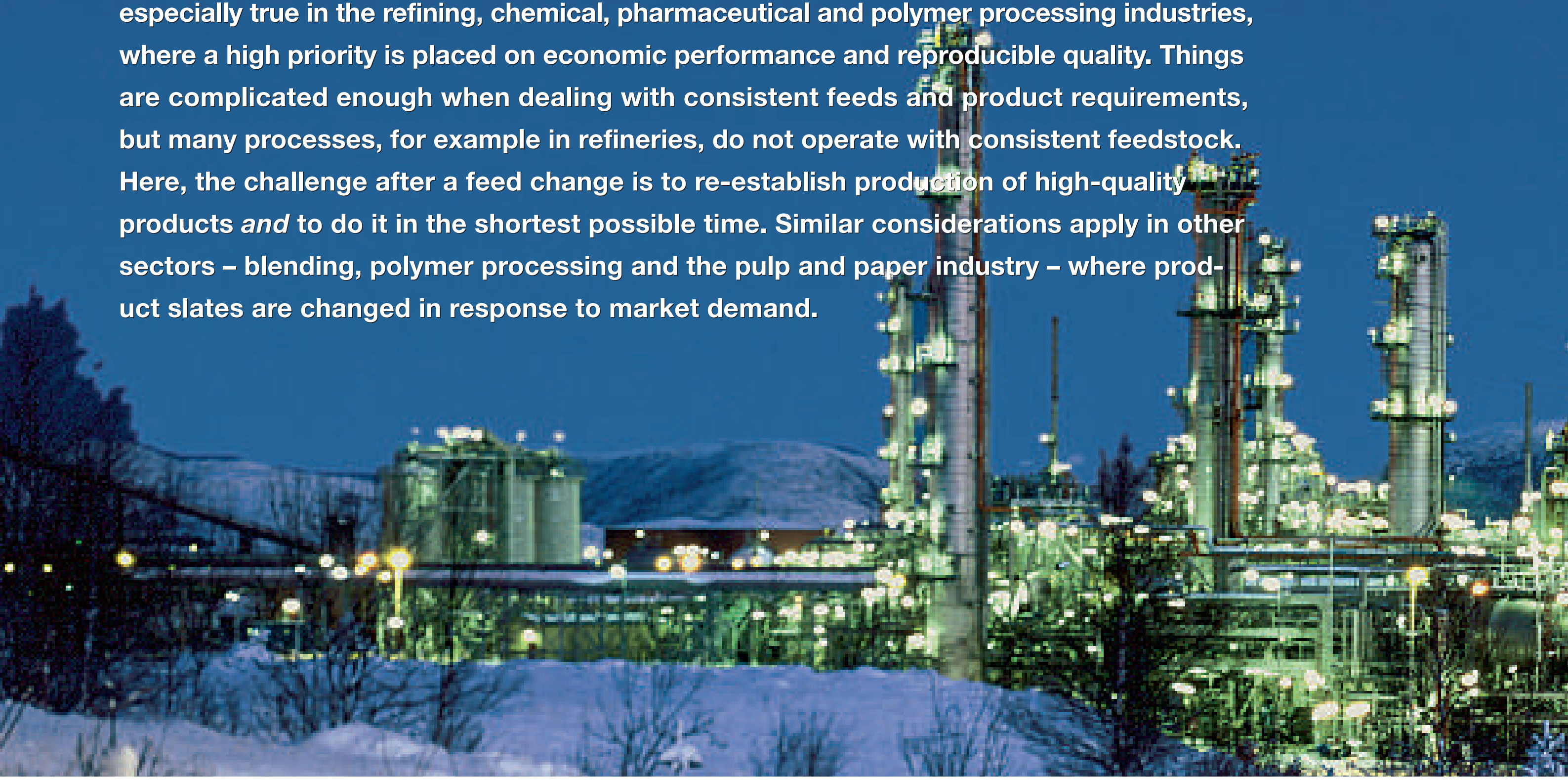
Tight quality control is essential in today's increasingly competitive marketplace. It is especially true in the refining, chemical, pharmaceutical and polymer processing industries, where a high priority is placed on economic performance and reproducible quality. Things are complicated enough when dealing with consistent feeds and product requirements, but many processes, for example in refineries, do not operate with consistent feedstock. Here, the challenge after a feed change is to re-establish production of high-quality products *and* to do it in the shortest possible time. Similar considerations apply in other sectors – blending, polymer processing and the pulp and paper industry – where product slates are changed in response to market demand.



Mathematical models are increasingly seen as an important, if not the only, means by which required performance and quality objectives can be met in an optimum way [1, 2]. The continuous advances in instrumentation and the decreasing cost of ever-more-powerful computational tools have made model-based solutions, such as predictive control, real-time optimization, online estimation, and process monitoring, not only technically feasible but also economically viable.

To meet growing market demand, ABB has developed a comprehensive suite of products for advanced process control (APC). As depicted in 1, this product suite includes:

OptimizeIT Dynamic Solutions (DS)
OptimizeIT Inferential Modeling Platform (IMP)
OptimizeIT Predict & Control (P&C)
OptimizeIT Loop Performance Manager (LPM)
OptimizeIT Advanced Blend Control (ABC)

Dynamic Solutions is a framework for advanced, first-principle process model development and execution, including simulation, estimation and optimization. Inferential Modeling Platform was developed to enable users to build inferential models, including neural network models, which can be deployed online and used as measurements for multivariable control. Predict & Control is a new generation of MPC[1] that is based on a multivariable state space model. Loop Performance Manager is used for monitoring and tuning of regulatory control loops, which often increases the performance and benefits of other APC products. Finally, Advanced Blend Control is used for blend order management and optimization, plus online property control. In the following, we will focus

[1] Model Predictive Controller
[2] For information on the other products, readers are referred to [3, 4].

suite

on two of these products[2)]: Dynamic Solutions and Predict & Control.

Dynamic Solutions framework

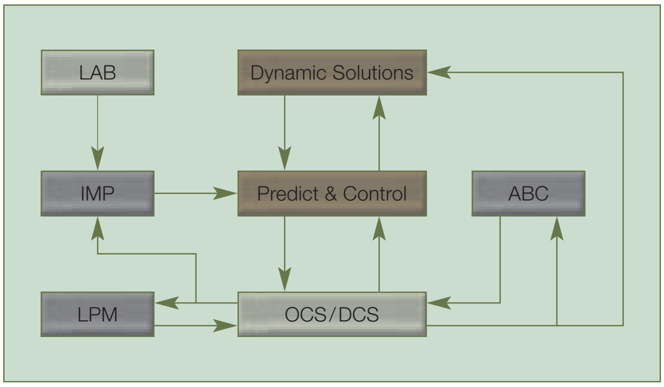
Until recently, solutions based on rigorous nonlinear dynamic models have not been thought to be feasible. Early techniques suffered from a lack of reliability and required the efforts of highly skilled engineers to develop. In short, the tools have simply not been good enough and the cost of model development and execution has been prohibitive. It has become clear that large-scale first-principle model development can be cost-effective only if a framework that supports block-oriented modeling is employed. This framework also needs to include robust numerical solvers, an adequate model library, and an open thermodynamic data server. OptimizeIT Dynamic Solutions is a result of that vision. Some of the features of Dynamic Solutions can be summarized as follows:

- Equation-based for multi-faceted applications
- A model library for basic process operation
- Graphic model builder based on Microsoft Visio
- Menu-driven commands
- PSE gPROMS as the solution engine
- Open thermo server
- Report generation
- XML as the data exchange format
- OPC data communication

Equation-based for multi-faceted applications

The advantages of the equation-based approach over the traditional sequential-modular approach are well documented. In short, with the equation-based approach, the description of the physical system is separated from the numerical solution method. Engineers can thus concentrate on the modeling aspect and let the selected solvers provide the numerical solutions. With the different sets of variables that are specified, and with the appropriate numerical solvers, the same model can be used for different applications, such as simulation, parameter estimation, data reconciliation and optimization.

1 Optimize[IT] APC product suite



Model libraries

The equation-based approach is not without its problems, the most critical of which are feasible specification, provision of initial values, and the so-called high-index problem – a form of numerical stability problem. However, all of these problems can be addressed to some extent with a carefully designed model library such as the one provided with the DS framework. With this library, a whole range of items can be modeled – from distillation columns through steam and heat exchangers to flow devices and gas turbines. Indeed, the provision of model libraries has been one of the key reasons for the wide acceptance of steady-state flowsheeting. Moreover, model modularization promotes ease of model maintenance and allows for the inclusion of more complex, customized models.

> Dynamic Solutions is a framework for advanced, first-principle process model development and execution.

The Dynamic Solutions framework has been successfully used to support the development of industry-relevant integrated flowsheet models. These flowsheets have been developed with the DS library models as well as with models developed specifically for different industries. The industries covered include pulp and paper, polymer, refining, petrochemical, and energy management. These models encapsulate ABB's extensive process knowledge and modeling expertise. Two of these flowsheet models are described in the following.

Catofin dehydrogenation

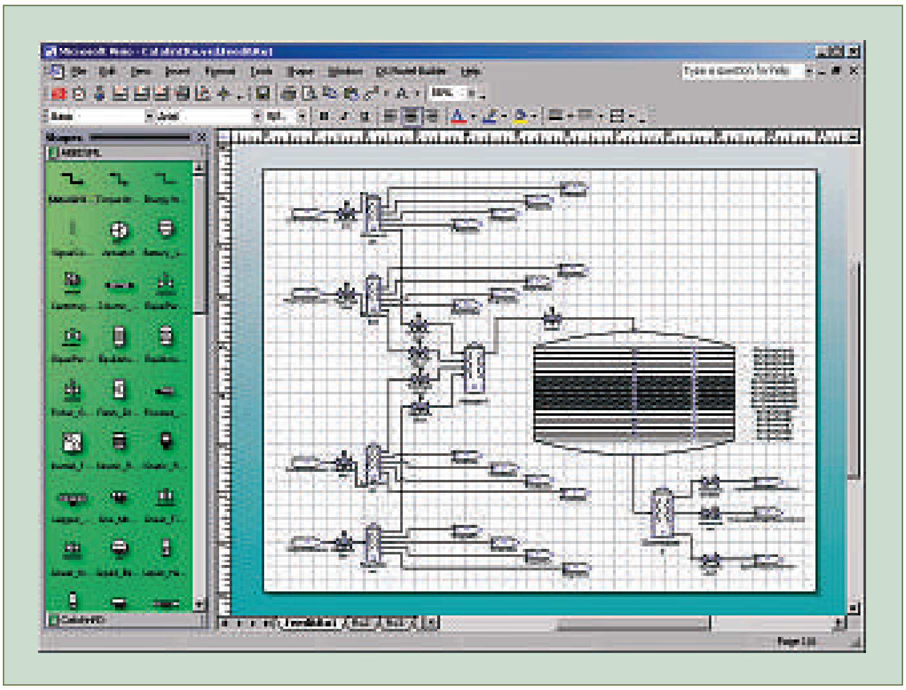
The ABB Lummus Catofin dehydrogenation process 2 is a fully flexible, state-of-the-art, world-scale process for the manufacture of propylene and butylene using high performance catalysts. The key to the plant performance is the reactor section. This section is split into several parallel reactors that are sequentially driven through staggered cracking and catalytic reactions, steam purging, and catalyst regeneration (coke burning) cycles.

It is highly desirable to optimize the sequence control schedule for this cyclic reactor operation. A first-principle model for the enhanced quantitative understanding of the process characteristics has been developed. It includes both chemical kinetics and diffusion mass transfer, as well as mass and energy balances. This rigorous model can be used to optimize the start and end time of each stage of the cyclic operations, as well as the various flow rates and operating pressure and temperatures. The benefits that can be derived from this optimization include increased selectivity, reduced utility usage, and improved operation of the downstream compressor and waste-heat reboiler.

Polymerization

Polyvinyl chloride (PVC) is one of the oldest polymers and, in terms of volume

2 Catofin flowsheet



manufactured, the second most common thermoplastics worldwide. Most PVC resins are produced by batch-wise aqueous suspension polymerization. This is an extremely complex process involving a large number of reactions as well as multi-phase heat and mass transfer. Consequently, it is difficult to achieve an optimum operation for this process 3.

Developing a PVC reaction optimizer that can maintain operating parameters close to the optimum more effectively than conventional control techniques has many benefits. Based on a rigorous model, the decision variables involved in an optimization in this case include a temperature profile (over time), the time and amount of initial and second initiator charge, and the amount of suspending agent. Potential benefits include reduced utility and raw materials usage, reduction in the frequency of 'short-stopped' batches, and optimization of the reactor cleaning frequency.

Predict & Control is a new generation of MPC that is based on a multivariable state space model.

Working with Predict & Control

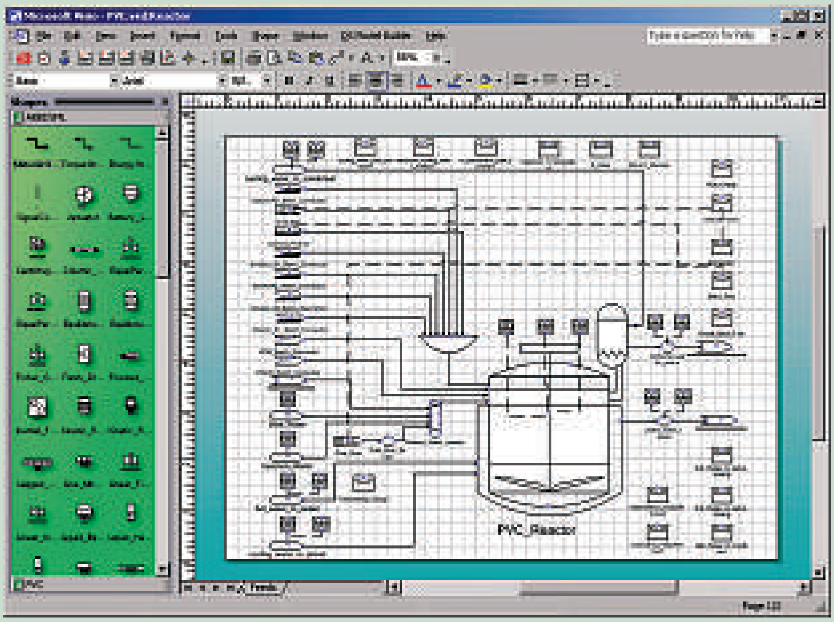
As evidenced by the previous discussion, Dynamic Solutions can be used as a stand-alone package for advanced modeling and optimization. It can also generate linearized models based on different steady-state operating conditions. The linearized models can be used by Predict & Control to provide control over a wider operating range. Dynamic Solutions can also perform as a non-linear optimizer for Predict & Control.

Predict & Control

Multivariable model predictive control (MPC) is a widely used industrial technique for advanced process control. As already mentioned, Predict & Control represents a new generation of MPC that is based on a multivariable state space model [5]. This controller offers several advanced features, including:

- Subspace identification methods to identify state space models.
- Kalman filter state estimator to provide better predictions and improved control performance.
- Prioritized ranking of constraints and optimization objectives.
- Scheduling of models and tuning parameters to handle non-linear dynamic processes.

3 PVC flowsheet

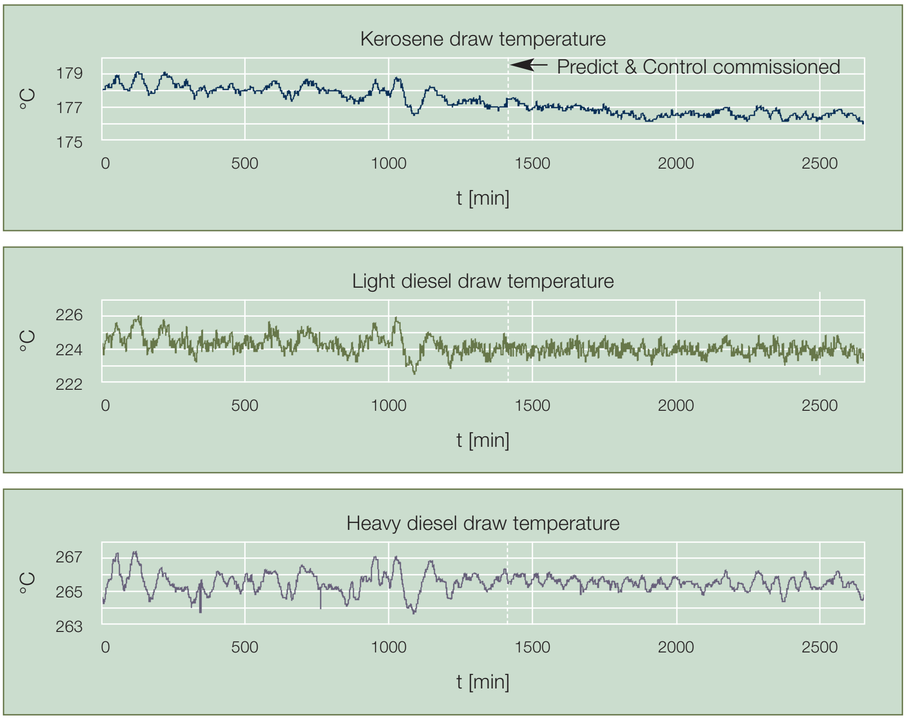


State-space modeling

The state space model allows for uniform treatment of stable, integrating and unstable processes, and also provides better representation of process variable interactions (the states may represent coupling). The Predict & Control modeling tools include powerful subspace identification methods to identify multivariable models from process data. The tools are also very flexible as they provide several ways to create models. For example, a model can be defined as a group of individual transfer functions, which are then saved as a state space model. Models may also be merged together. Model gains and delays can be edited. A state space model can also be obtained as a linearized version of a rigorous model created in Dynamic Solutions.

The state space model also permits the controller to apply a Kalman filter for online state estimation. The Kalman filter computes the best estimates of the system states using the model, noise statistics, and online process variable measurements. The controller uses the state estimates and the model to provide dynamic future predictions of the effects of unmeasured disturbances on all process variables. This methodology provides much more accurate predictions than the independent, static offset estimates used in most other MPC technologies. Better predictions lead to better control performance. In addition, extra process variable measurements can be used as feedback to further improve the feedforward capabilities of state estimation. Also, when creating a state space model as a linearized version of a Dynamic Solutions (DS) model, unmeasured disturbance variables represented in the DS model (eg, feed composition, reaction rates, ambient temperature) can be included as inputs in the controller model. The online state estimator uses this information along with prediction errors from the available online measurements to estimate the effects of these unmeasured disturbances. Early detection of such disturbances can greatly reduce their potential future effects on the controlled variables.

4 Improved temperature control

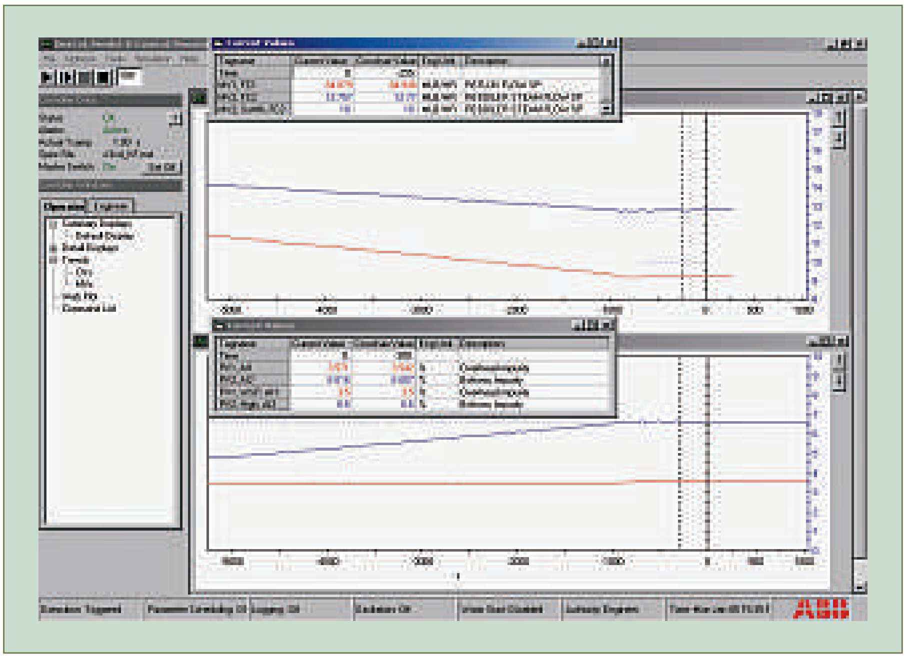


Refinery crude unit control

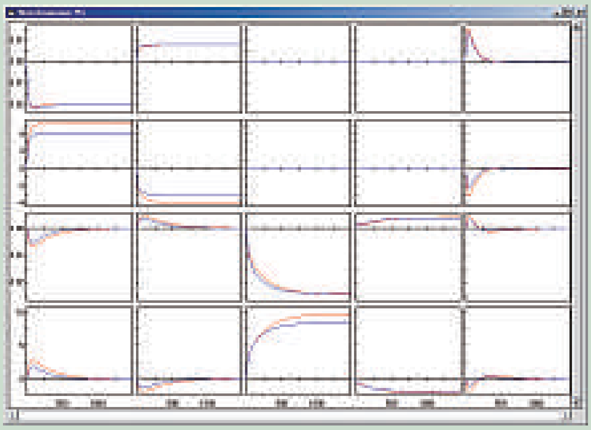
The Predict & Control controller has been implemented on a refinery crude unit with the main objective of providing quality control of the product streams [3]. The product quality control layer also employed inferential models using IMP. The controlled variables included the three draw temperatures (kerosene, light and heavy diesel), which are controlled to setpoint, along with additional constraint variables. These variables are controlled using seven manipulated variables, including the setpoints for the draw rates and pumparound flows as well as for the crude heater outlet temperature.

The flexibility of the state space controller provided superior performance to overcome an operational problem. The heater fuel BTU content is not very stable, causing consistent 3–4 °C peak-to-peak temperature swings in the heater outlet temperature. The period of oscillation is of the order of 30 to 40 minutes and the regulatory controls could not be adjusted to eliminate the disturbance. To improve the control, the heater outlet temperature measurement is added to the model as feedback. The resulting temperature control is shown in 4, and indicates a significant improvement over the existing control.

5 Constrained optimization



6 Separator train step responses for different feed rates



Optimization and constraints

Another advantage of Predict & Control is the ability to handle multiple constraints and optimization objectives in a prioritized manner. Constraints are assigned to priority classes that represent how important it is to satisfy the constraint. The prioritization prevents tradeoffs between high- and low-priority constraints when the controller is over-constrained. Optimization objectives may be represented using MV (manipulated variable) soft constraints, which are also assigned to priority classes, but must be ranked below the high-priority constraints and setpoint control objectives. Alternatively, optimization may be represented as a linear program with costs for each variable. In either case, the constrained optimization approach prevents deterioration of control performance when trying to satisfy optimization objectives.

> The APC suite provides a comprehensive solution for model-based applications, including technologies for modeling, control and optimization.

Distillation control

5 shows the controller applied to a distillation column. The optimization objective is to minimize steam usage while controlling the overhead impurity to a setpoint and satisfying maximum limit constraints for the bottoms impurity and the column differential pressure. The controller slowly reduces the steam (blue trace in upper plot) and also adjusts the reflux (red trace in upper plot) to maintain the overhead impurity close to setpoint (red trace in lower plot) while not violating the bottoms impurity constraint (blue trace in lower plot).

Parameter scheduling

Predict & Control also includes methods for handling non-linear, dynamic processes. In particular, the controller supports parameter scheduling for online switching between specified sets of models and tuning parameters based on a scheduling parameter. Multiple linear models can be easily generated from a non-linear DS model to represent different operating conditions.

Separator train control

The DS software has been used to model a separator train process for an oil production platform. The feed to the separators is often unstable due to multiphase flow from wells, subsea manifolds and multiphase pipelines connecting remote wellhead platforms to the production facility. In addition, the feed rate often fluctuates significantly. Multiple linear models for Predict & Control have been generated from the DS model at different feed rates. 6 shows the dynamic step responses. The online controller is able to switch between the multiple models based on the measured feed rate to improve control performance.

A comprehensive solution

The ABB APC suite includes several software products for various model-based applications. All of the APC suite products are Industrial^{IT} certified and can communicate with Inform^{IT} and other open automation, data acquisition and historian systems. Open connection standards supported include OPC, OLED B, SQL and COM. The product suite provides a comprehensive solution for model-based applications, including the most advanced technologies for modeling, simulation, control and optimization.

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