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Summary

A typical requirement on simulation models, being software application components that need to interact with other simulation components, is compliance with interface standards. One of the challenges of the international simulation community is to enable simulation models to run in any simulation tool, independent of which tool was used for model creation.

In aerospace industry simulation models are often developed with Commercial Off-The-Shelf (COTS) tools like MATLAB[®] / Simulink[®] / Stateflow[®], MATRIXx[®] and Statemate[®]. Transfer from a COTS tool to another simulation environment may require time-consuming adjustment of the simulation model by the model developer. The National Aerospace Laboratory NLR has developed for ESA/ESTEC the Model-Oriented Software Automatic Interface Converter (MOSAIC) tool. MOSAIC automatically transfers simulation models from MATLAB/Simulink to the real-time simulation tool EuroSim. It has been experienced that automatic model transfer with MOSAIC significantly reduces time, cost, effort and error-prone source code editing.

Currently, MOSAIC is being used in the aerospace industry. NLR uses MOSAIC in several simulation projects. In this paper a number of MOSAIC applications will be discussed, specifically the use of MOSAIC in model development for the Affordable Digital Fly By Wire Flight Control Systems for NLR's Flight Simulator. At NLR, MOSAIC is also part of the Computer Aided Control Engineering (CACE) working environment ISMuS. ISMuS acts in part as a model repository. Moreover, various COTS tools are available to build simulators using simulation models. Therefore the automated simulation model transfer capability of MOSAIC is an important ISMuS facility for model developers.

Further enhancements of MOSAIC are envisaged and are based on user requests.

MATLAB/Stateflow is often used to add finite state machine theory to Simulink models.

MOSAIC v2.0 will be able to transfer MATLAB/Simulink/Stateflow models to EuroSim.

MOSAIC v3.0 will be able to automatically transfer models from

MATLAB/Simulink/Stateflow to the ESA's Simulation Model Portability (SMP) standard. The SMP standard facilitates the reuse and portability of simulation models between different simulation systems. The simulation models interact with each other and with the simulation environment by means of services that are provided by the Simulation Model Interface (SMI) component software of the SMP standard. Future versions of MOSAIC that are considered, concern model transfer from COTS tools such as MATRIXx and Statemate to EuroSim and to SMP.



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1 Introduction

The development of a simulator is a complex process that involves the integration of several simulation models. These simulation models are often created using a variety of COTS tools. Since the simulation models are software application components that need to interact with other simulation components, they need to be compliant with interface standards of simulation environments. Therefore, one of the challenges of the international simulation community is to enable simulation models to run in any simulation environment, independent of which tool was used for model creation.

Model transfer from one environment to the other is usually a time-consuming process, if done by hand. It also includes the risk that errors are created when editing the model source code. To support model transfer the National Aerospace Laboratory NLR has developed the Model-Oriented Software Automatic Interface Converter (MOSAIC) tool. MOSAIC v1.0 has been developed for ESA/ESTEC. MOSAIC v1.0 automatically transfers simulation models from MATLAB/Simulink to the real-time simulation tool EuroSim, see figure 1. MATLAB/Simulink is a COTS tool that is often used by the aerospace industry to develop simulation models. EuroSim [12], on the other hand is a configurable simulator tool that is able to support all phases of space and non-space programmes through real-time simulations with a person and/or hardware-in-the-loop. The combination of MATLAB/Simulink, MOSAIC and EuroSim is very suitable for model development from feasibility study to real-time operation. It has been experienced that in this combination MOSAIC plays an important role in projects because it significantly reduces development costs and time.

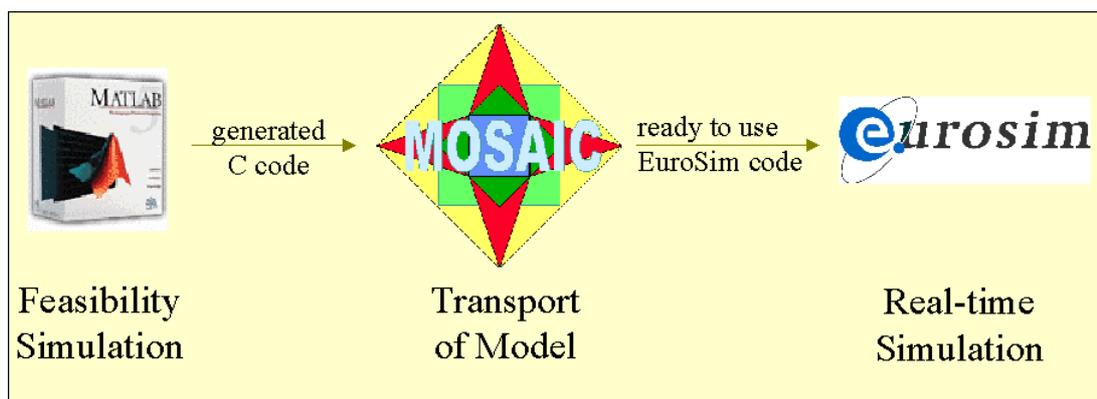


Figure 1. Automated model transfer with MOSAIC



2 MOSAIC Design Philosophy

The design of MOSAIC is based on the philosophy that models are the product of complex design cycles in projects and have been verified and validated with project requirements in mind. Therefore, as a first and basic design issue, MOSAIC will not change anything in the source code that intervenes, or changes in any way the mathematical logic of the model.

Another issue is the use of numerical integration routines for real-time simulation. MOSAIC treats the mathematical model logic and the numerical integration routines as separate source objects. It is possible to let MOSAIC implement solver routines that are different from the ones used in the original Simulink model. In this way MOSAIC facilitates the achievement of specific real-time simulation requirements of a model outside the model development COTS tool.

MOSAIC v1.0 takes as input model source code that has been generated by the Real Time Workshop [5] from a Simulink model. The output of MOSAIC v1.0 consists of model source code that can run in EuroSim, as well as additional EuroSim specific files. Although a user experiences MOSAIC as a one step tool (see figure 1), MOSAIC has been designed in a modular way. As a first step the Simulink generated source code passes an interface module. This delivers source code that can in principle be used in EuroSim. However, execution of model source code in EuroSim also requires for example schedule information, mission information and API information to be present. Hence, MOSAIC performs a second step that generates for instance a schedule file, a mission file and also automatically generates API information. Figure 2 depicts the schematic description of the MOSAIC modules. A detailed description of the MOSAIC design can be found in [2]. The modular design of MOSAIC also facilitates possible future extension of MOSAIC transfer capabilities from and to other COTS tools and simulation standards.

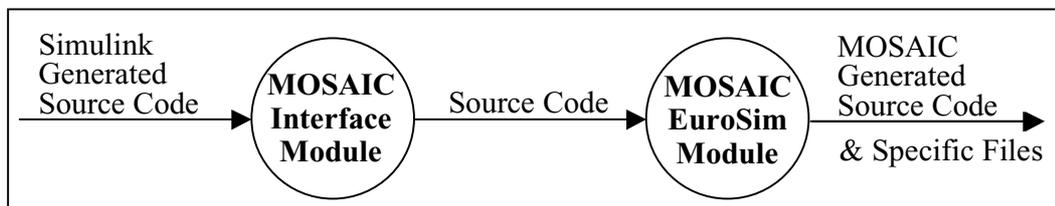


Figure 2. Schematic description of the MOSAIC modules

3 Using MOSAIC

There are several ways for a model developer to execute MOSAIC. One can execute MOSAIC from a Graphical User Interface or from the command line. To illustrate how model transfer with MOSAIC takes place from the Graphical User Interface, the actual use of MOSAIC is described in the paragraph below.

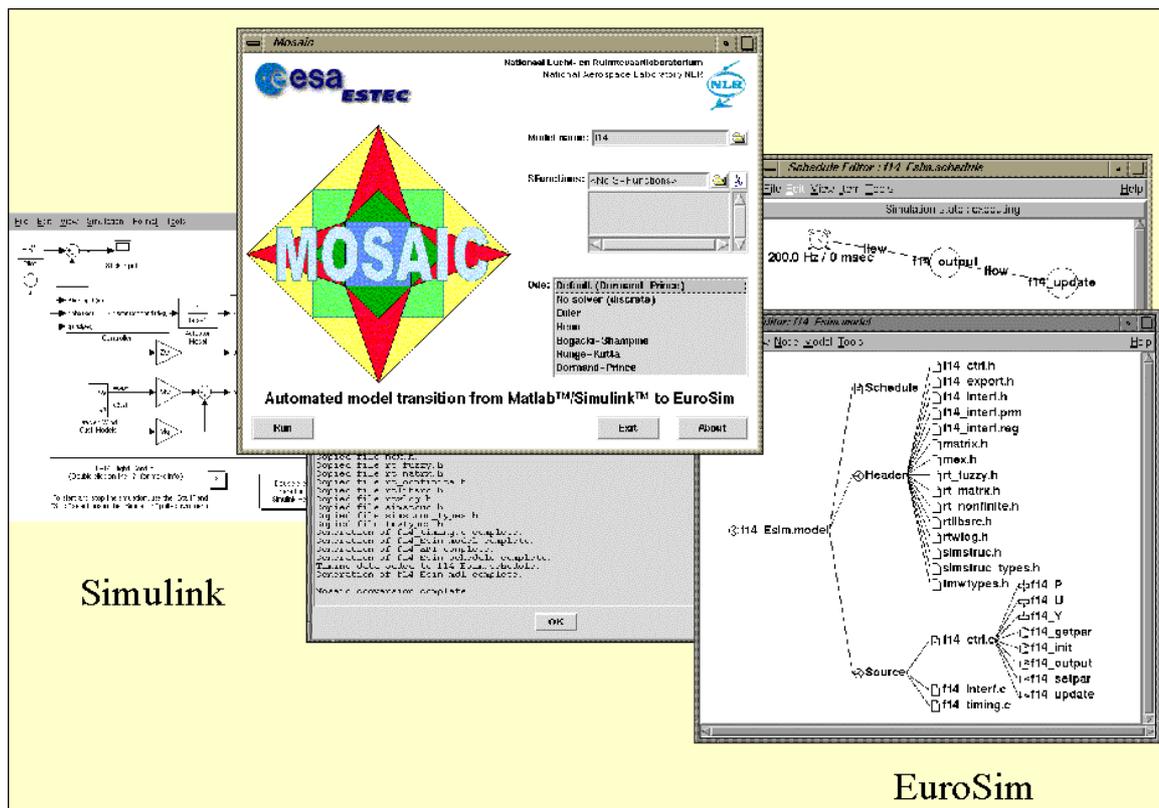


Figure 3. Screen capture of the Graphical User Interface

- To start a model transfer, a user types the name of the Simulink model in the model name entry field or browses to this model with the directory button next to this field and double clicks on the model name.
- Next, MOSAIC displays the names of the S-functions that are used in the Simulink model. A user may change these references if desired. Following the MOSAIC design philosophy, MOSAIC itself does not alter the S-functions, but will include proper references in the generated EuroSim model.
- Third, the user selects a numerical ODE solver. If the option 'default' is selected, the solver information is taken identical to the one referenced in the original Simulink model.



The MOSAIC model transfer process is fully automated. The Software User Manual [3] of MOSAIC explains in detail the preparation of the simulation model transfer process in MATLAB/Simulink, the actual model transfer process, and suggestions for further model customisation in EuroSim.

4 Test Results of MOSAIC

In order to test the full functionality of the MOSAIC tool, a varied set of Simulink models has been used. The test model set includes models of continuous systems, discrete systems and hybrid systems (i.e. combination of continuous and discrete systems).

Since MOSAIC does not change the mathematical model, the simulation results of the C code generated with the RTW, which is the input to MOSAIC, must be the same as the simulation results of the C code generated with MOSAIC, which is the output of MOSAIC. Only minimal differences due to numerical precision based on the computer hardware are allowed. For every model the test results show no differences in numerical values to the last digit of the numerical precision, see [4].

One of the test case models concerns the Simulink example of an F14 flight control system and aircraft model. Figure 4 shows the simulation results for the calculation of the pilot G-force in Simulink and in EuroSim. For test results of the other models, see [4]. All test cases have delivered good results and prove that continuous, discrete and hybrid systems are successfully converted by MOSAIC.

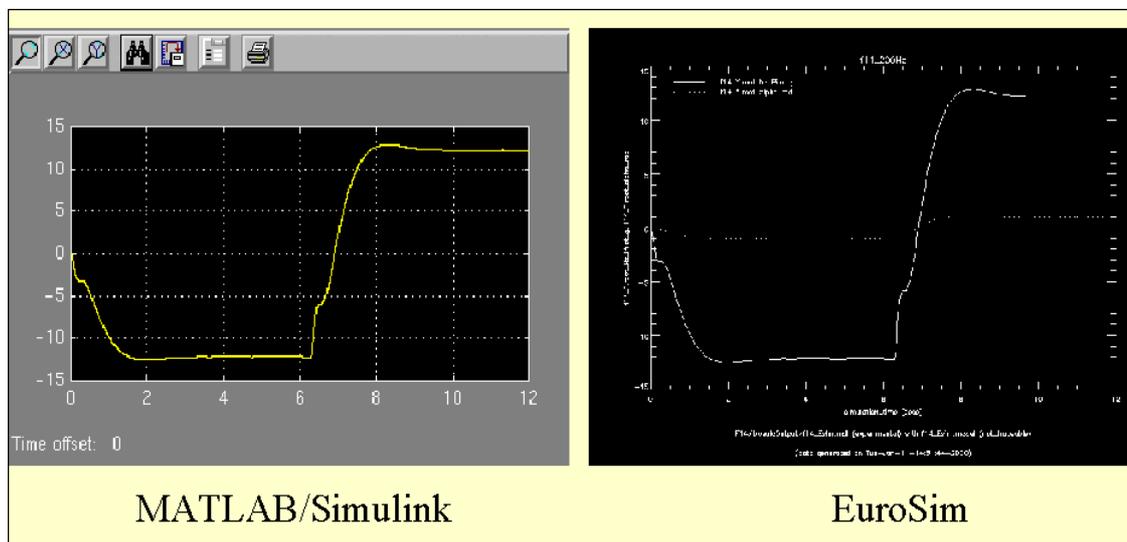


Figure 4. Simulation results in Simulink and EuroSim for the f14 model (screendumps)



5 Application of MOSAIC in Simulation Projects

Currently, MOSAIC is used in the aerospace industry. Aerospaiale evaluates the use of MOSAIC in the Automated Transfer Vehicle (ATV) project [6]. NLR uses MOSAIC in several simulation projects, for instance for model development in the Affordable Digital Fly By Wire Flight Control System (ADFCS) project [7] for NLR's Flight Simulator. The goal of this project is to develop an architecture for affordable fly-by-wire (FBW) digital flight control systems for small commercial aircraft. Models of flight control systems are created by ADFCS partners all over Europe with MATLAB/Simulink. NLR transfers the MATLAB/Simulink models of the aircraft with MOSAIC and implements them in the simulator. For the implementation the real-time simulation environment ProSim [9] is used. ProSim is an instantiation of EuroSim that has been adapted to the NLR flight simulator. From the ProSim environment the ADFCS simulation models are connected to other simulator components like a motion system, visual system, mock-up system etc. It has been experienced that automatic model transfer with MOSAIC significantly reduces time, cost, effort and error-prone source code editing in the ADFCS project.

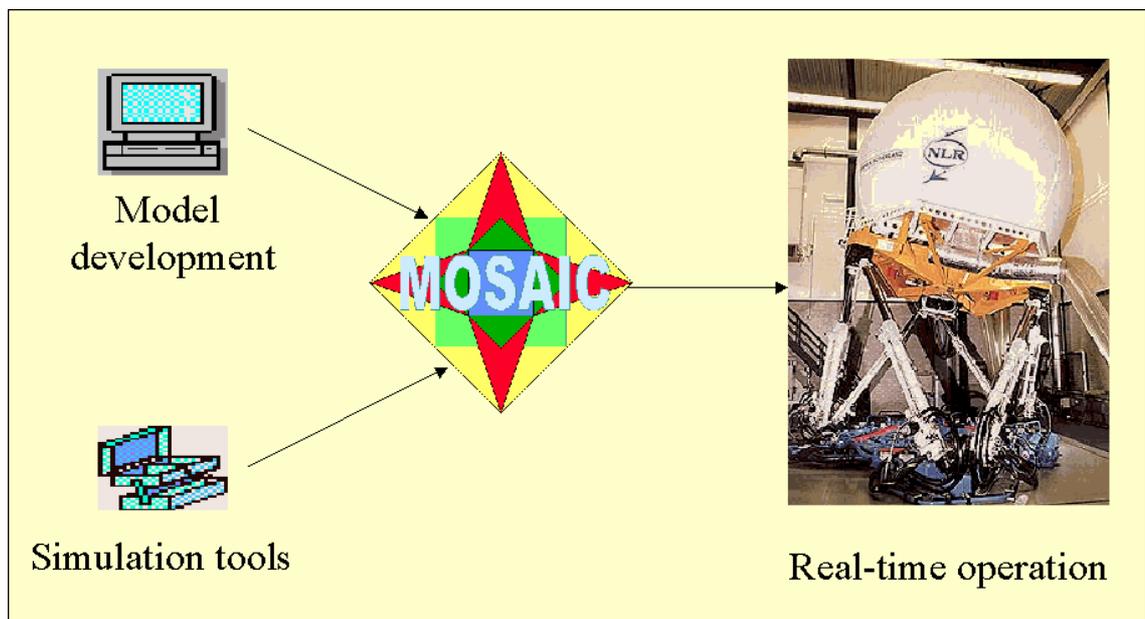


Figure 5. Application of MOSAIC: the ADFCS project

Further enhancements include the provision of MOSAIC as plug-in to the envisaged EuroSim 'Model & Simulator Repository' (M&SR) facility. The M&SR facility will be available in future releases of EuroSim. In this way an interface is facilitated within EuroSim to simulation models that have been created by other COTS tools than EuroSim, like MATLAB/Simulink.

6 Embedding MOSAIC in a CACE Infrastructure

At NLR, MOSAIC is an integral part of the CACE working environment ISMuS [10]. ISMuS (Information System to support the development of digital simulation models for Multibody Systems) facilitates easy exchange of knowledge between various people and their CACE projects. ISMuS acts in part as a model repository. Various COTS tools are available to build simulators using the simulation models. Although the tools can be located on various machines, using different operating systems, ISMuS appears to the model developer as one single virtual computer. ISMuS is an instantiation of SPINEware [8], a tool developed at NLR to create applications area working environments.

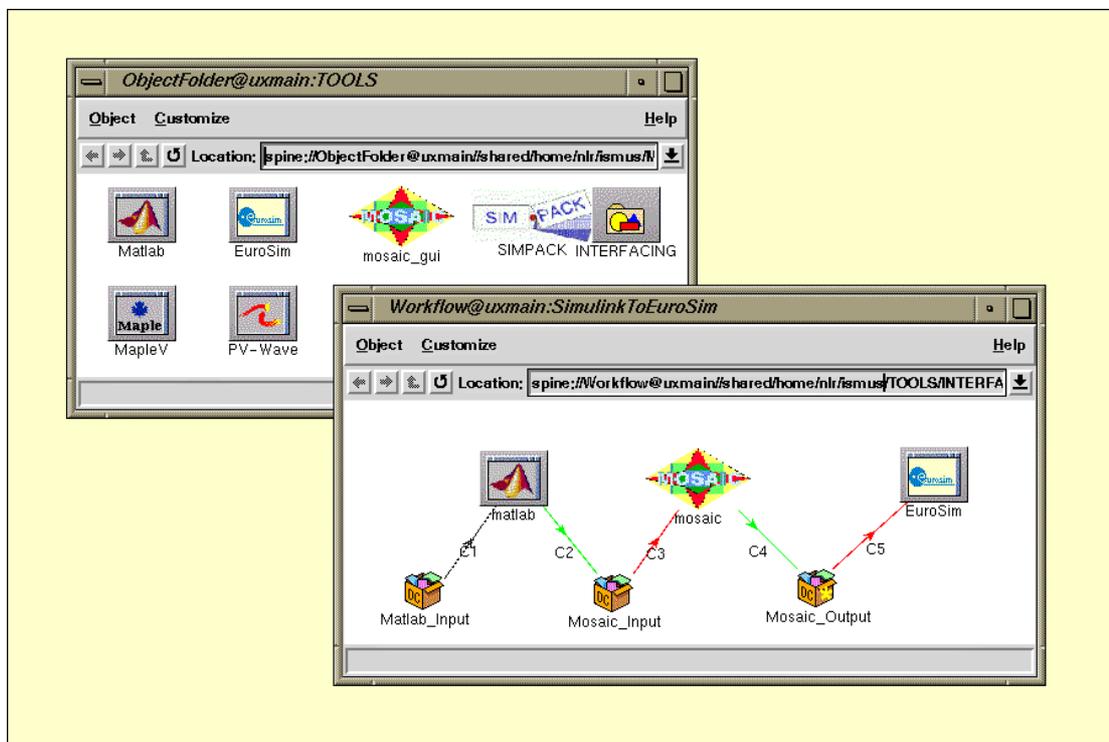


Figure 6. User interface to MOSAIC from the CACE working environment ISMuS

The automated simulation model transfer process capability of MOSAIC is crucial for the model developers. Therefore MOSAIC is an essential asset of ISMuS. Moreover, to further aid model developers, the transfer process with MOSAIC appears in the form of a so-called workflow, see figure 6. In the ISMuS workflow the tools MATLAB, MOSAIC and EuroSim are chained in such a way that the whole model transfer process is executed automatically. The tools in the workflow are triggered automatically when their input boxes are filled with data. The model developer starts the simulation model transfer process using the workflow by double



clicking on the MATLAB icon. Once the MATLAB input box is filled with a model, MATLAB/Simulink will automatically start-up with this model. Within MATLAB/Simulink the model can be edited following the guidelines of the MOSAIC User Manual [3], and subsequently the Real Time Workshop is started. After the Real Time Workshop has finished code generation and the user has exited MATLAB, the MOSAIC input-box is filled, again automatically, with model transfer data. From here the model transfer process continues automatically to and including the start-up of EuroSim. In EuroSim the model developer can start simulation activities using the EuroSim model editor. From here he can immediately build a simulator using the automatically created EuroSim model by MOSAIC.

Integration of the model transfer process into an automatically executable workflow significantly reduces time and effort. It eliminates repeating and boring jobs that require the same actions time and again. No time is lost with transferring model files manually from one system to the other.



7 MOSAIC Enhancements

Due to successful application in the aerospace industry MOSAIC will be extended with new features based on user requests. In the near future the following new capabilities of MOSAIC are planned:

- Model transfer from MATLAB/Simulink/Stateflow to EuroSim.
- Model transfer from MATLAB/Simulink/Stateflow to the ESA's Simulation Model Portability (SMP) Standard,
- Model transfer from MATRIXx to EuroSim and SMP,
- Model transfer from Statemate to EuroSim and SMP.

Stateflow is a MATLAB facility for the implementation of state transition diagrams of finite state machines. Similar to Simulink it is possible to generate source code from a Stateflow diagram. Stateflow diagrams can be integrated with Simulink models. MOSAIC v2.0 will take as input model source code generated from Simulink that contains Stateflow diagrams and automatically transfer the model to EuroSim.

The SMP standard [1] of ESA facilitates the reuse and portability of simulation models between different simulation systems. The simulation models interact with each other and with the simulation environment by means of services that are provided by the Simulation Model Interface (SMI) component software of the SMP standard. MOSAIC v3.0 will be able to automatically transfer models from MATLAB/ Simulink/Stateflow to the SMP standard.

In aerospace industry MATRIXx and Statemate are also often used for model development. Future versions of MOSAIC that are considered, concern model transfer from COTS tools such as MATRIXx and Statemate to EuroSim and to SMP.



8 Concluding Remarks

NLR has developed the simulation model transfer tool MOSAIC. MOSAIC is used in the aerospace industry. It has been experienced that automatic model transfer with MOSAIC significantly reduces time, cost, effort and error-prone source code editing. A feature of MOSAIC is that it does not in any way affect the mathematical logic of a model. Simulation results before and after a transfer with MOSAIC are identical up to machine level.

MOSAIC naturally fits into the virtual CACE working environment. Integration of the model transfer process into an automatically executable workflow reduces time and effort even more. It eliminates repeating and boring jobs that require the same actions time and again. No time is lost with transferring model files manually from one system to the other.

The first release of MOSAIC allows automatic model transfer from MATLAB/Simulink to EuroSim and can be controlled from a Graphical User Interface. Future enhancements of MOSAIC capabilities are planned.

Information on MOSAIC can also be found on [11]. More information on NLR's approach to generic simulations can be found in [13].



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