The Latest Developments of the ANSA Preprocessor for IGA Applications of LS-DYNA®

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Abstract

Iso Geometric Analysis (IGA), is maturing and becoming capable to be incorporated in industrial applications. Widely used in the automotive industry for crash analysis, LS-DYNA is the first commercial solver to provide IGA features. Better accuracy, potential shorter run times, accurate geometry representation make IGA effective for crash analysis. Nevertheless, the complexity of the current automotive models and the maturity of the already established methods and processes require the development of the respective IGA tools and processes to reach and exceed the current levels of effectiveness. The new technical challenges give the opportunity for new solutions and improvements in engineering simulation technology.

During the last year ANSA has developed the needed tools and algorithms to successfully convert CAD geometry to IGA ready part descriptions, thus making the first successful complex hybrid IGA - FEA models possible. We continue our work towards full integration of IGA in current complex LS-DYNA FEA crash models and processes. All latest development will be presented.

From CAD to CAE, the current Process in the Automotive Industry

The current processes for Finite Element Analysis (FEA) simulation model build up in the automotive industry starts from CAD data import, translation, geometry clean up, and meshing. In the next phase the FE meshes are connected in subassemblies and the subassemblies are assembled to the final models. Meshing is a complex geometric transformation performed by specialized software like ANSA. During the "meshing" procedure a great deal of information from the CAD side is lost, since the discretization that is needed is only an approximation of the original geometry. Moreover, the semantics of the various CAD entities must be mapped onto the new FE entities which is not always possible. The procedure itself is also time consuming. ANSA has been designed from the ground up capable of handling geometry and FE at in the same model in parallel, thus trying to bridge this gap. Unfortunately, the predominant use of FE only processes and data flows have always proved a barrier between the design and analysis worlds.

Various methods have been developed in the past years to avoid meshing. Isogeometric analysis is one of them. The idea behind IGA is that since there is already a mathematical description of the domain's geometry the same description could be used for approximating the solution fields. Specifically, since CAD uses non-uniform rational B-Splines (NURBS) for geometry representation the same functions could be used as basis functions. NURBS have higher continuity and it has been shown that they have very good properties for analysis [2,3]. Thus, analysis can be performed on the CAD geometry, resulting in a much faster procedure that captures in the best way the intentions of the designer and the analyst, while at the same time removes the discretization errors. LS-DYNA first introduced the *ELEMENT_SHELL_NURBS_PATCH in 2010 and since then has been advancing its IGA support.

Fig.1: B Pillar CAD geometry and resulting FE Mesh.

The path from CAD Geometry to IGA Ready Geometry

IGA uses the same basis functions as CAD, namely non-uniform rational B-Splines (NURBS). The automotive parts though, are in a form that is not suitable for IGA. They are not watertight; they are modelled as solid (B-Rep) and contain a very large number of trimmed surfaces. Most of these problems have already been addressed for the classical FE mesh generation. In the already established processes of the industry, robust practices are in place for mid-surfacing (translating the solid B-rep representation to a shell), and geometry clean up.

Nevertheless, the remaining geometry representation of a part consists of multiple trimmed surfaces. For example, in the automotive industry some parts can contain 5000 patches (surfaces with different mathematical representations) or even more. Such an example is the B Pillar depicted in Figure 1. Focusing on the detailed area, it becomes obvious that there are many unnecessarily small patches to describe the geometry (Figure 2). IGA though can only be performed on single untrimmed surfaces. LS-DYNA has added the capability to solve trimmed surfaces in 2014. So, the problem remains to convert the trimmed multi-patched part into a trimmed single-patched geometry. This is the IGA ready geometry.

Figure 2: B Pillar with many different patches.

To overcome this issue, we developed an algorithm to minimize the number of patches required for representing the complex physical domain of the industrial applications.
The first step is to create a mapping between the initial geometry and a non-periodical surface. Periodical surface is a surface that is periodic in at least one direction. An example of a periodical surface is the cylinder where in one direction the surface is repeated periodically. This mapping is called 2D mapping or parametrization. However, this is not always possible due to topological restrictions. If the starting geometry is not topologically equivalent to a non-periodical surface, then this process cannot be performed. In these cases, the starting geometry must be divided into smaller regions. A general example of the physical space and the created underlying surface is shown in figure 3.

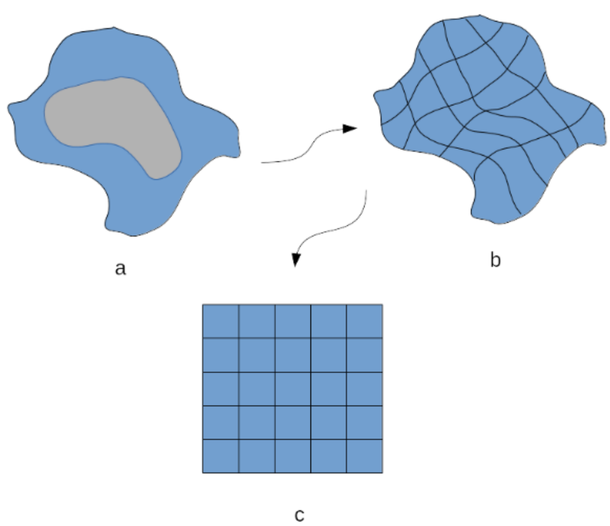

Figure 3: Mapping the initial geometry to a parametric surface. a) The initial geometry in gray color and the underlying mathematical representation. b) The parametric surface that is extracted. c) The structured parametric space of the surface.

The boundaries of the surface can be defined at the extent of the initial geometry. In this case, the physical domain is defined as a part of the resulting surface (trimming). In cases where there are holes or highly non-convex boundaries trimming is unavoidable, or even impossible, if our goal is a good quality mapping. The quality of the parametric space that is extracted determines the speed and success of the whole procedure. In most industrial cases the use of a trimmed surface description is the only feasible way to produce structured surface geometry.

The second step of the process is the representation of the extracted geometry as a parametric surface. Since both CAD and LS-DYNA use B-splines to represent parametric surfaces this is our point of focus. B-spline surface is a widely used surface type that is simple and can be exactly converted to various other surface types. The disadvantage of the B-spline surface is that a local refinement comes with a big increase in stored data. Our algorithm finds the complexity of the underlying geometry and decides the appropriate knot vectors that will be used to maintain the accuracy while minimizing the memory used. The knot vectors determine the size of the resulting elements. There is the possibility for the user to add specific characteristics and limitations about the resulting elements. For example, the user can request a surface with uniform element size (uniform knot vectors) in a specific value range.

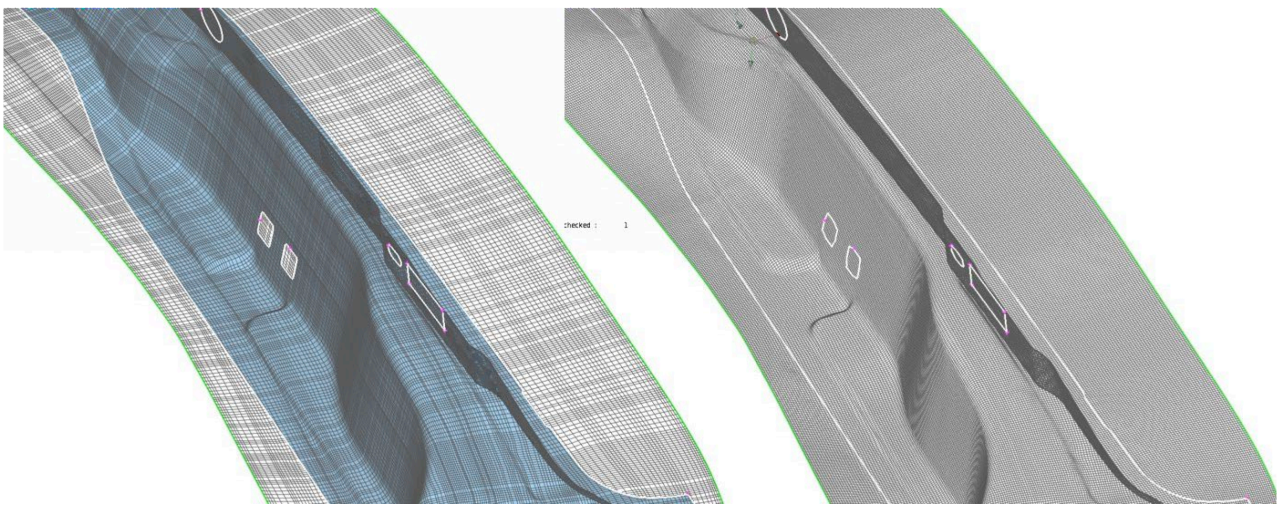

Fig.4: Two different parametrizations of a B-Pillar. Coarse, variable density knot vector and uniform dense knot vector

In the final step, the surface is validated, and the initial surface representations are replaced by only one. During this process small geometric discontinuities originated from the translated CAD geometry are fixed. Due to the build-in property of B-spline surfaces, the resulting geometry has a higher order continuity, which will be preserved in the solution with the IGA method. After the creation of the IGA ready geometry, the geometric representation is ready to be exported from ANSA with the new LS- DYNA keywords for IGA.

Thus, the mesh generation phase of the traditional will be replaced with the IGA ready geometry generation which although computationally complex, is from the user perspective much more automated and offers significant time gains. In the current version of ANSA this is a “one click” operation.

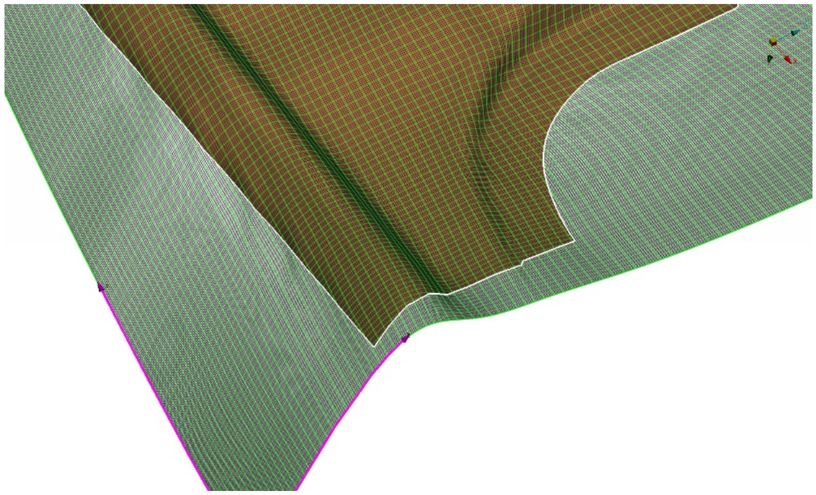

Figure 5: Detail of a IGA ready trimmed surface representation of a B-pillar

Multi patched parts

The mapping of a complex part to a trimmed surface although tempting and aesthetically desirable due to the inherent simplicity, has its own set of problems.
First and foremost, not all parts can be mapped to one surface. Parts that have cuts and flaps cannot be mapped.

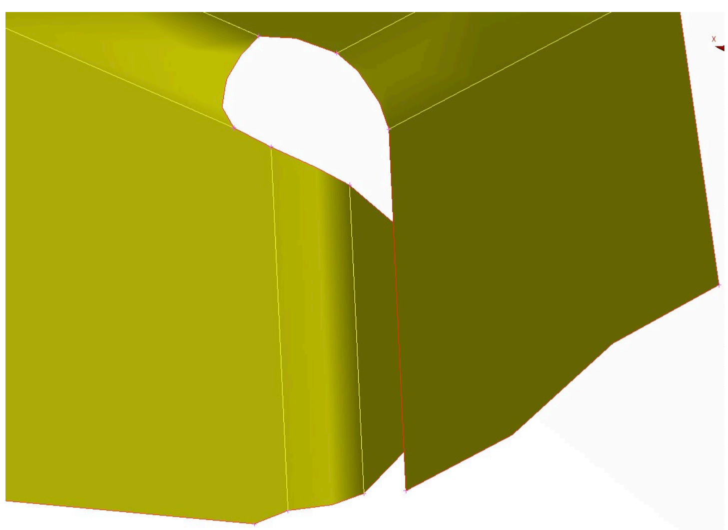

Figure 6: Example of a part that cannot be mapped on a single surface

Moreover, the existence of features that are not aligned with the principal directions of the parametric surface will produce a locally dense knot vector that will be projected across the parametric space and thus result in an overly dense knot vector (see Figure 7 a). This in turn, will increase the computation time during the solution. The way this problem has been tackled until now is by using different kinds of splines, such as T-Splines or Hierarchical splines, that can be locally dense to capture the geometry features. CAD though uses B-Splines and the use of a different spline technology will deviate from the premise of analysis on the CAD geometry.

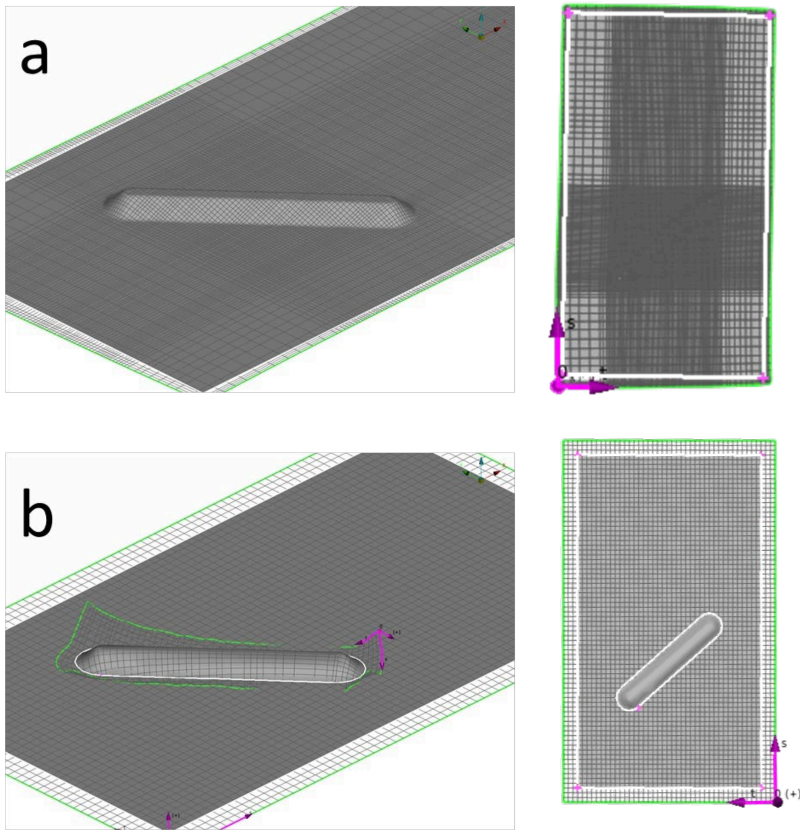

Fig.7: Effect of non-aligned feature on the knot vector density: a) Single surface, b) Multiple surfaces

The approach followed by LS-DYNA in the latest version, implements a penalty method for connecting patches, initially developed and introduced by the TUM group in the IBRA method [4]. The resulting contact connects the neighboring patches albeit with reduced C0 continuity (see figure 7 b).

It is thus important to minimize the number of different patches and resulting contacts since the drop of continuity introduces simulation inaccuracies, that are not consistent with the purpose of IGA.
The introduction of this new method for describing a part with multiple connected trimmed surfaces introduces the need for a new format that resembles a CAD format since it contains not only surface parametric description but topology information as well.
New keywords have been introduced and they will be rolled out in the next versions of LS-DYNA and ANSA.

Moving forward, pre-processing on geometry and hybrid models

Although in research up until now, a lot of attention has been focused on the meshing procedure and on the simplification an IGA methodology would introduce to the current procedures. One should not underestimate the effort and resources needed for the creation of the final model of such a complex analysis such as this for Crash. Although it is tempting to apply the same methodologies to the new paradigm, we should take advantages of the new possibilities to come up with better ways to setup our model. Having a pure geometric description of the model provides new opportunities for a better definition of all those needed elements that connect the model, apply the loads, and set up the boundary and initial conditions. Not only we can remove the current discretization phase that inserts approximations, but we can better capture the intention of the analyst or the designer when all model entities are defined and attached to the original geometrical entities.
The natural way to do this, is by leaving behind the standard practice of applying constraints and loads on nodes, but rather apply them directly on geometry primitives, such as curves and subsets of surface knot vector spans. This needs new developments both in pre-processors and the solvers. The result though will be the much faster and accurate creation of the model based on the original CAD data and information, and the easier geometry modification and parametrization by the analyst during the development process.

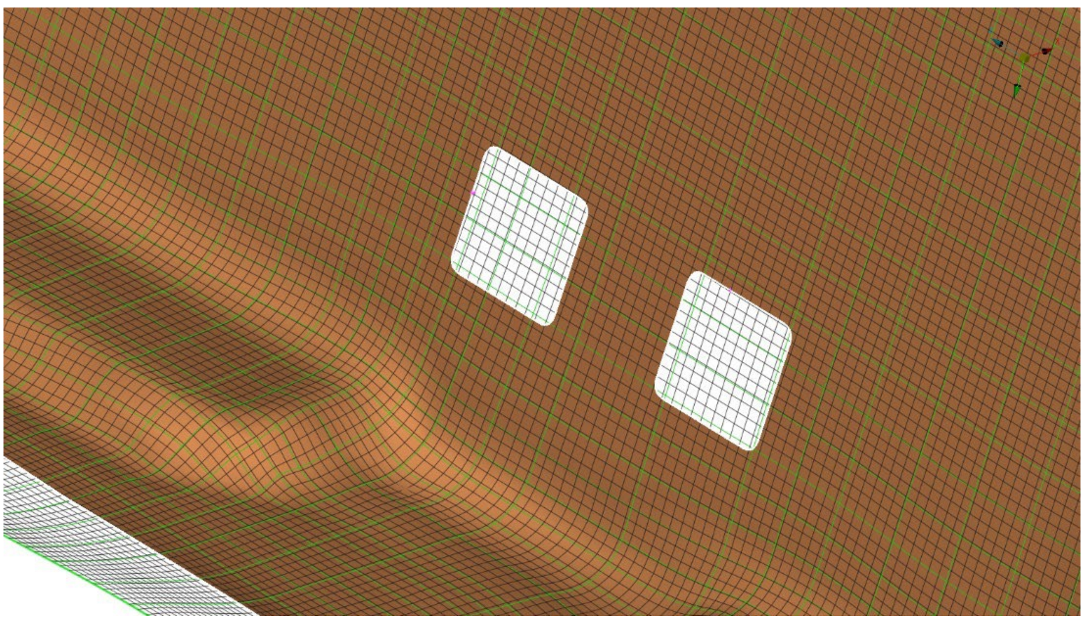

Figure 8: Holes defined by trimming curves. Constraints and Boundary conditions will be referencing them.

The need for such new methodologies leads us to the design of new formats and data structures that will capture the new requirements. Full geometric descriptions have to be included in the solver input decks. Moreover, existing keywords describing constraints, loads, initial and boundary conditions, have to be generalized in order to be applicable to geometric entities such as edges, surfaces and parts of them.

The great advantage though of working with IGA methods using industry standard tools like LS-DYNA and ANSA is that one can plan for a transitioning phase between the current FE methodologies and the upcoming IGA. The best way to do so, is to make possible the creation of hybrid FE - IGA models. This way the analyst can:

- use his existing validated and trusted FE models as a starting point
- try IGA methodologies replacing few parts in the FE model
- optimize and experiment with IGA modelling options
- build trust and expertise on the new technology
- extend the use of IGA further in the models while at the same time having the option to switch back to FE

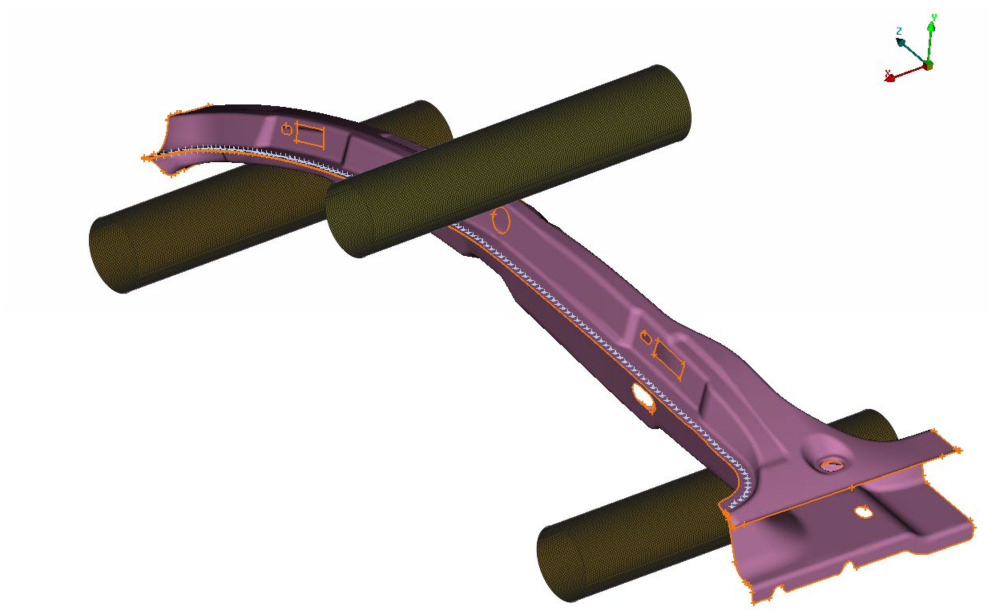

Figure 9: Hybrid FE - IGA LS-DYNA 3Point bending model of a B-Pillar, impactors and spot welding in FE while the main B-Pillar parts are IGA

The way LS-DYNA keywords and the respective representation and methods are implemented in both LS-DYNA and ANSA makes easy to build and handle such models. Spotwelding for example is done in exactly the same way either FE or IGA representations are selected in the pre-processor. Moreover, new options for Heat Affected Zones are added to the solver to take advantage of the IGA.

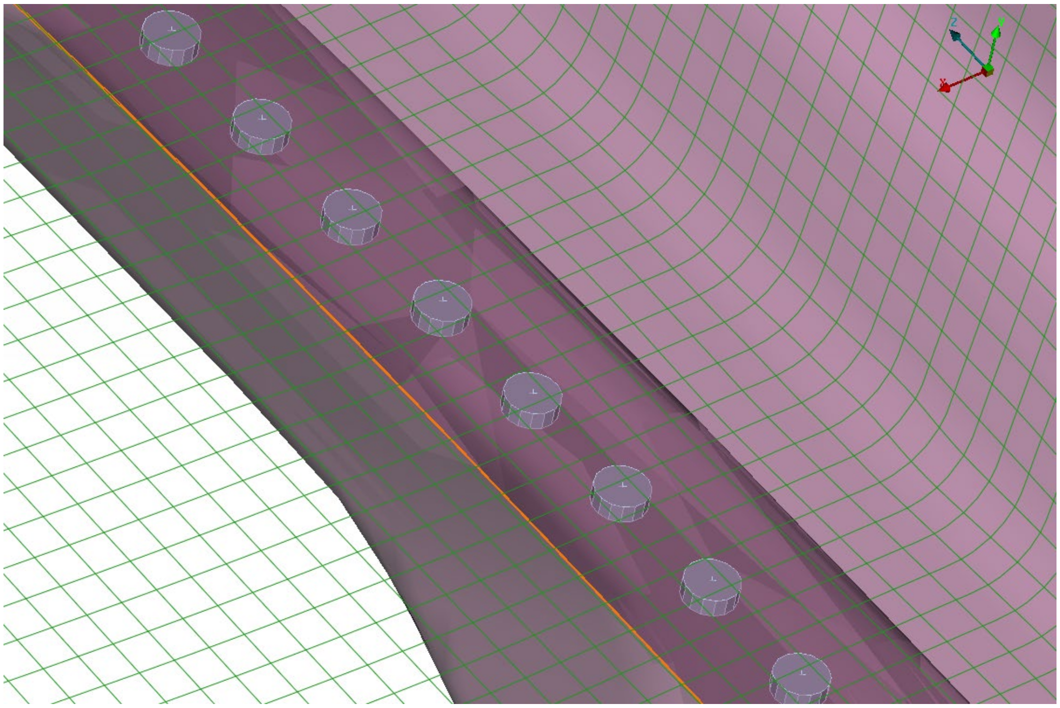

Figure 10: Hybrid FE - IGA LS-DYNA Model, IGA parts spotwelded with FE elements

Conclusions

During the last year BETA CAE Systems put a lot of effort developing new tools and extending existing ones to help the industrialization of the IGA. Our method can automatically create an IGA friendly representation of the CAD translated geometry and create a LS-DYNA model. This process can coexist with the FEA. New models can be created, compared with existing ones to steadily validate the IGA method and ultimately replace the FEA method. We are adapting all our modeling tools to be aware of the new technologies, making the transition for the analysts as easy and transparent as possible.

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