LS-DYNA® Meshfree Interactive Adaptivity and Its Application

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Abstract

The meshfree adaptive method has been developed and widely used as an important tool to deal with large topology change with severe local deformation in the application of 3D metal forming analysis. However, due to the complexity of material deformation, it is impractical to predefine the adaptivity before the actual analysis is performed. The interactive adaptivity will be an alternative to dynamically detect distortion and maintain the quality of meshfree discretization.

In this work, we are going to present a new development on meshfree interactive adaptivity. Several control indicators are introduced to measure the local distortion in discretization as material deforms. When one or more indicators are beyond certain tolerance, which indicates the occurrence of severe shear deformation, large volumetric change, or unbalanced nodal distribution, meshfree interactive adaptivity is triggered. The user defined tolerance is carefully adjusted according to the history of material deformation to avoid the over-activation of interactive adaptivity. Several numerical examples will be presented to demonstrate the advantages of interactive adaptivity and compared to the traditional approach.

Introduction

Meshfree adaptivity **[1]**-[6] has become an important tool for the structural analysis involving large deformation. During the adaptive process, discretization is optimized according to material deformation and moving interface, so that the numerical simulation gets enhanced in accuracy and robustness. In LS-DYNA®, the meshfree adaptive procedure [2]-[4] adopts the built-in feature of meshfree method to construct local interpolation function with high order smoothness and consistency for the transfer of state variables between the successive deformations, which maintains the desirable accuracy and minimizes the numerical diffusion. However, the nature of adaptivity brings up some numerical issues. For example, the high gradient of state variables could be dramatically smoothed out if adaptivity is over-activated. The existing implementation of adaptivity, referred as the traditional adaptivity in this paper, is controlled by a predefined timetable, which limits its application to the problem with complex and unpredictable deformation.

In this paper, we present a new development of interactive control for meshfree adaptivity, which is designed to capture distortion and trigger adaptive procedure dynamically. Three different indicators are currently introduced to identify distortion from different sources. Other error indicators and estimators can also be incorporated for more general application in the future. A new control keyword, *CONTROL_REMESH_EFG, is created to provide users with the flexibility to control the interactive adaptivity and define the corresponding tolerance. The interactive adaptivity currently was implemented for EFG 4-node solid element, and the extension to other element types is straightforward. We demonstrate the capability of this new development by analyzing several metal forming and machining problems.

Interactive Adaptivity

In the interactive adaptivity, it is very important to properly measure distortion as material deforms. We introduce three indicators to detect local distortion:

(1) Indicator of shear deformation: the off-diagonal entries of deformation gradient tensor are used to measure the shear deformation from the reference configuration updated by the previous adaptivity; most of metal forming problems are usually shear-distortion dominant.

(2) Indicator of volumetric change: this indicator is particularly useful for the problems involving material damage.

(3) Indicator of unbalanced nodal distribution: the ratio of maximum and minimum edge lengths for every integration cell is used to represent the nodal distribution. The built-in mesh generator updates the discretization with good quality control after every adaptive procedure, which provides a smooth nodal distribution. The distribution changes as material deforms. Unbalanced nodal distribution will cause accuracy and robustness issue in meshfree approximation.

In the card 3 under the new keyword, *CONTROL_REMESH_EFG, user defines the tolerance for three indicators, separately. Interactive adaptive procedure is triggered when any one of three indicators has value beyond the tolerance. The default tolerance turns off the corresponding indicator. In order to deal with rapid topology change, we calculate the rate of indicator value change over every time step, and trigger additional interactive adaptivity if it is over certain tolerance.

In the card 2, we provide user with different choice to control the interactive adaptivity:

(1)the traditional adaptivity.

(2)the interactive adaptivity combined with the traditional one, where additional adaptivity is triggered interactively within every time interval of predefined adaptivity.

(3)the purely interactive adaptivity, where the time interval between two successive adaptive steps is bounded by ADPFREQ (in the card 1 of keyword *CONTROL_ADAPTIVE).

(4)the purely interactive adaptivity.

Numerical Examples

1. Wheel Forging

In this problem, the deformable part is modeled by 4-node solid EFG elements. The effective plastic strain in the final deformation is plotted in Figure 1. The computational efficiency comparison of the interactive and the traditional adaptivity is shown in Figure 2. As we can see, the interactive adaptivity reduces the overall computational time by dynamically detecting distortion and triggering much less number of adaptive procedures. Figure 3 and 4 compare the resultant contact force and internal energy results respectively which are in good agreement.

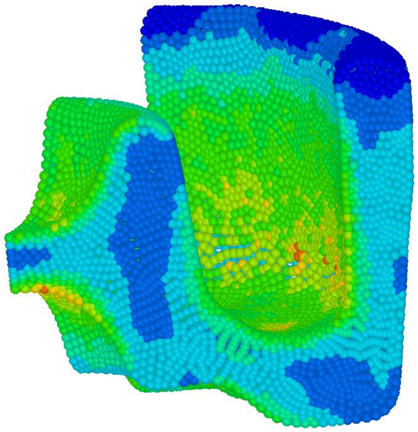


Figure 1. Contour plot of the effective plastic strain for wheel forging problem

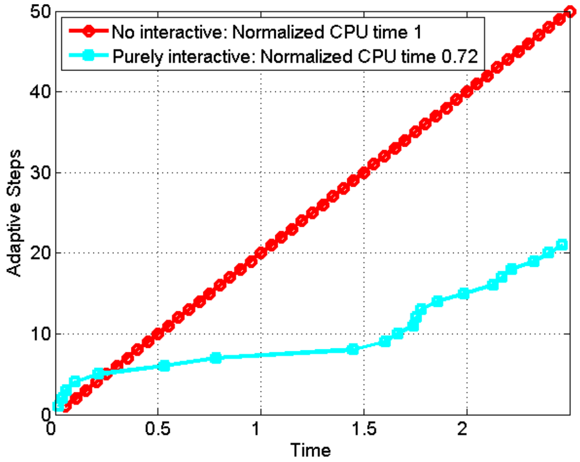


Figure 2. Computational efficiency comparison

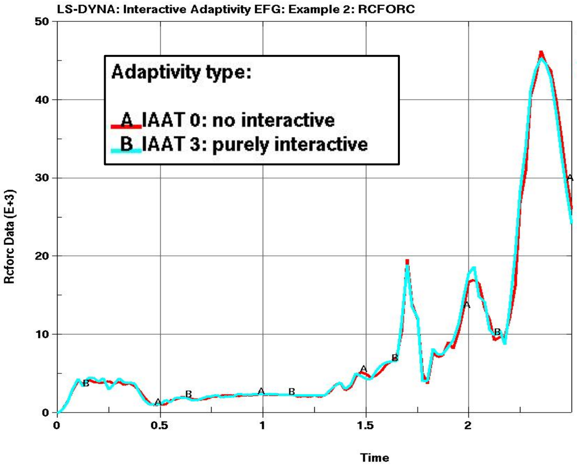


Figure 3. Comparison of resultant force

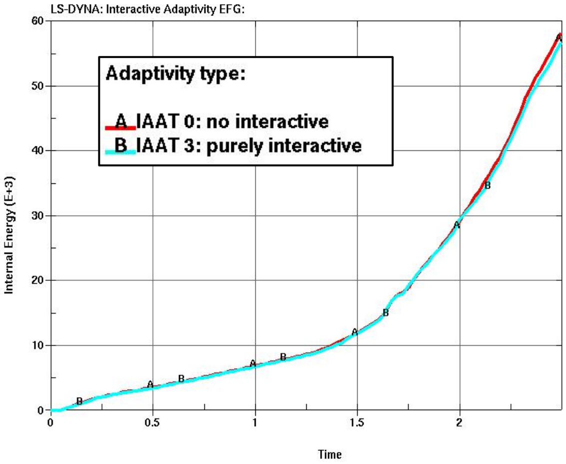
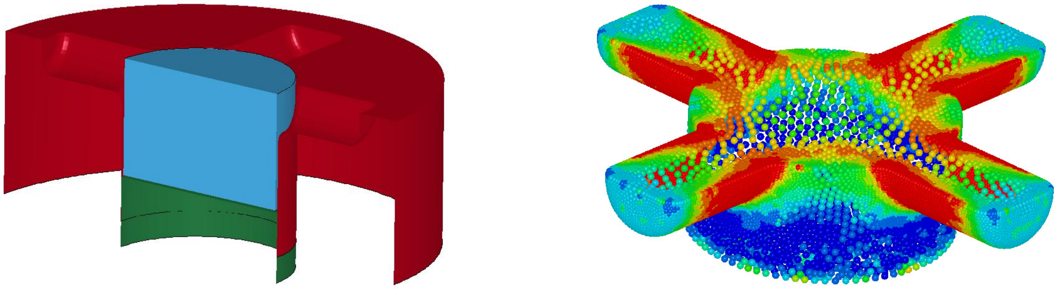


Figure 4. Comparison of internal energy

2. Cross Joint Extrusion

The half model of the work piece is shown in Figure 5 (a). After the extrusion process, the effective plastic strain in the final deformation is plotted in Figure 5 (b). In Table 2, we provide the CPU time comparison of the interactive and the traditional adaptivity, where the interactive adaptivity achieves remarkable enhancement in computational efficiency. Figure 6 shows resultant contact force between the work piece and the punch, and Figure 7 shows the internal energy of the work piece. Figure 8 is the history of volume change for the two methods. It is obvious that the conventional adaptivity predicts a slightly softer response than the presented method due to the loss of volume caused by the excess numbers of adaptive procedures.



(a) half model in the initial stage (b) contour plot of the effective plastic

Figure 5. Cross joint extrusion problem

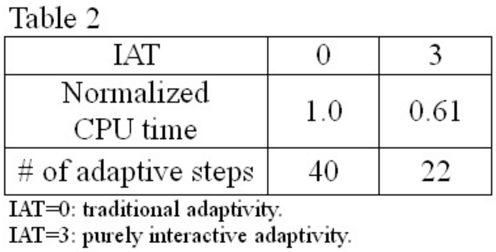


Table 2

IAT	0	3
Normalized CPU time	1.0	0.61
# of adaptive steps	40	22

IAT=0: traditional adaptivity.
IAT=3: purely interactive adaptivity.

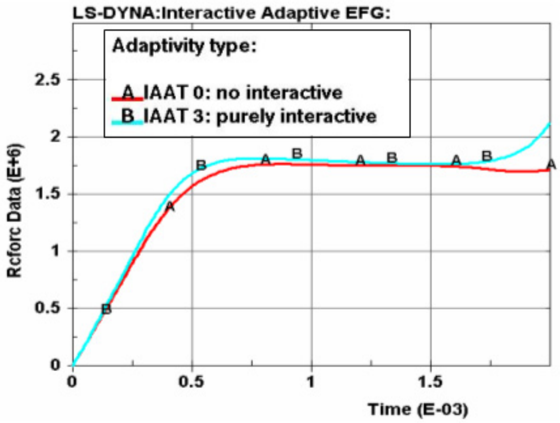


Figure 6. The comparison of resultant force

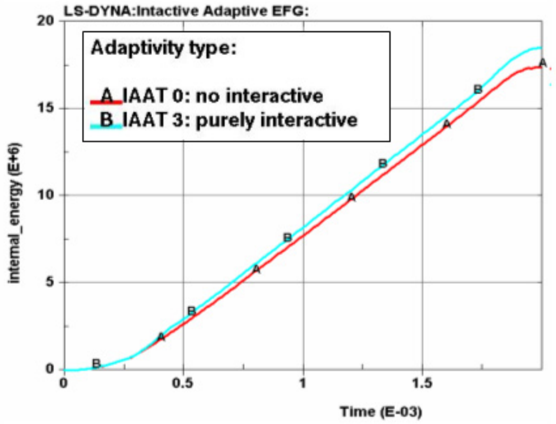


Figure 7. The comparison of internal energy

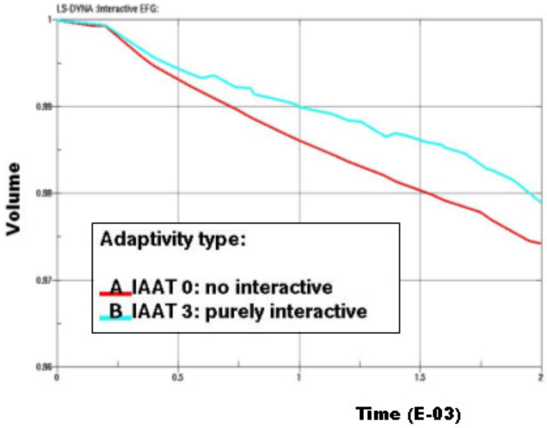


Figure 8. The comparison of volume change

3. Gear Forging

This forging problem has complex geometry profile, which can not be handled easily by the traditional meshfree adaptivity. The purely interactive adaptivity has been implemented together with the parallel version of 3D EFG, which provides effective analysis for this problem. The distribution of effective plastic strain is plotted in Figure 9. The occurrence frequency of distortion detected by purely interactive adaptivity is highly irregular, as shown in Figure 10, which explains the difficulty of using predefined timetable for the traditional adaptivity.

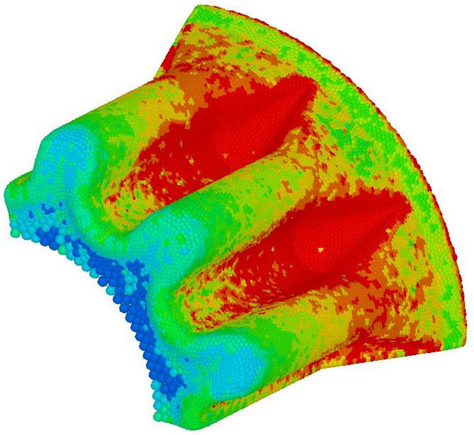


Figure 9. Contour plot of the effective plastic strain

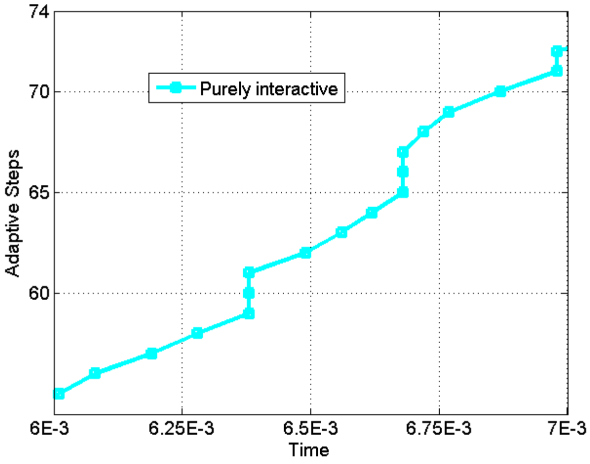


Figure 10. Purely interactive adaptive steps

4. Metal Cutting

Compared to forging and extrusion problem, metal cutting analysis is more challenging because it involves material softening and failure. The distortion problem due to continuum material damage is handled by using meshfree interactive procedure with a new development on surface separation scheme. Figure 11 shows the deformation and effective plastic strain distribution at different time during the cutting process. The high gradient is clearly captured in a local region along the cutting surface, which is very important for the spring-back analysis in the next phase of machining process. The resultant force is plotted in Figure 12.

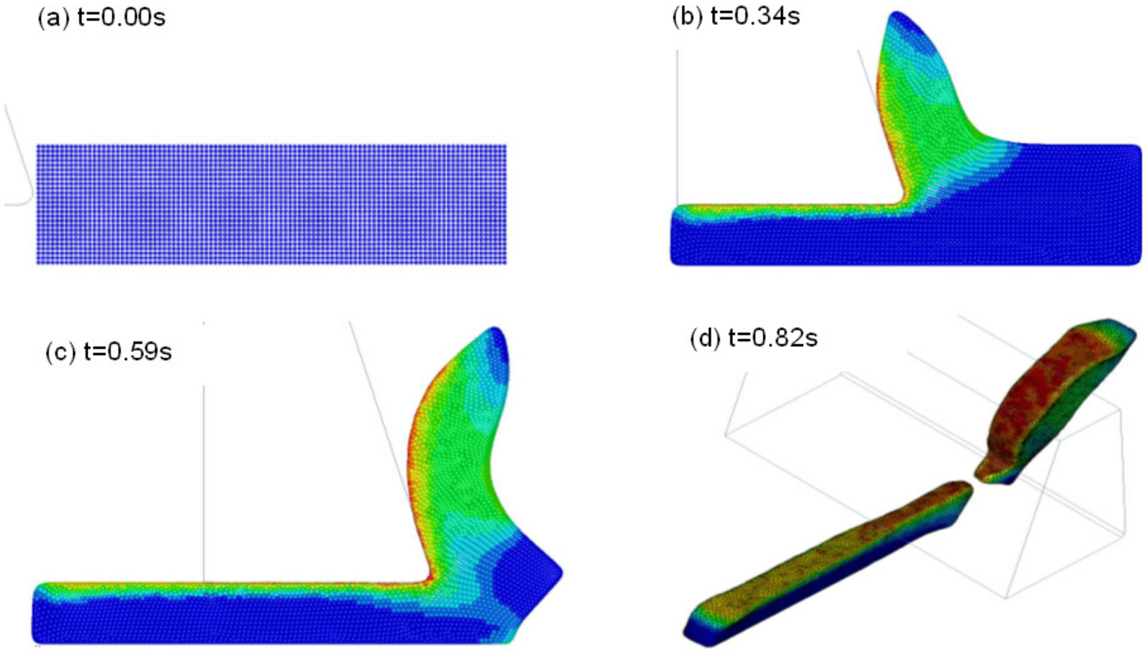


Figure 11. History plots of deformation and effective plastic strain distribution
(a)-(c) the side view of work piece; (d) the bird-eye view of work piece with the integration cells

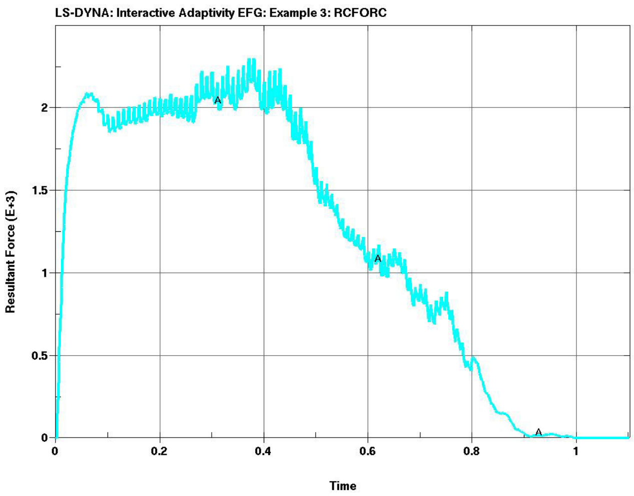


Figure 12. Resultant force in metal cutting problem

Conclusion

We have introduced the meshfree interactive adaptivity in recent developments, and demonstrated its capability for the application of metal forging, extrusion and cutting problems, which are usually difficult for the conventional adaptivity. The meshfree adaptive method is an accurate and robust method for the problems involving high gradients, large topology change and the requirements of precise surface presentation. With the new developments on interactive control and surface reconstruction, the performance of adaptivity is further enhanced on efficiency and accuracy. Nevertheless, the presented method has limitation on predicting the material failure and separation with a high degree of accuracy. It is still quite challenging to avoid mesh sensitivity issue as well as handle complex failure paths in the three-dimensional case. Finding a suitable physics-based failure model is another critical issue, which may require multi-scale approaches to model the subscale material failure pattern. This will be the continuation of our research and development.

Acknowledgement

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References

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