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An Exodus II Specification for Handling Gauss Points

D. Thompson, P. P. Pébay, and J. N. Jortner

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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D. Thompson
Sandia National Laboratories
M.S. 9152, P.O. Box 969
Livermore, CA 94550, U.S.A.
dcthomp@sandia.gov

P. P. Pébay
Sandia National Laboratories
M.S. 9051, P.O. Box 969
Livermore, CA 94550, U.S.A.
pppebay@sandia.gov

J. N. Jortner
Sandia National Laboratories
M.S. 9012, P.O. Box 969
Livermore, CA 94550, U.S.A.
jnjortn@sandia.gov

Abstract

This report specifies the way in which Gauss points shall be named and ordered when storing them in an EXODUS II file so that they may be properly interpreted by visualization tools. This naming convention covers hexahedra and tetrahedra. Future revisions of this document will cover quadrilaterals, triangles, and shell elements.

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Contents

Figures

Tables

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An Exodus II Specification for Handling Gauss Points

1 Introduction

This document specifies a naming convention for Gauss points so that applications that use those can communicate values computed at each Gauss point to visualization and post-processing tools. The naming convention is specific to element variables — as opposed to nodal variables — in the Exodus II file format [SY95]. The need for such a naming convention arose in particular from Salinas [BPR+02], a Sandia structural analysis application, which allows stress and other integrated variables to change continuously over each element. Currently only a single value is saved to disk after the computation.

1.1 Gauss Points

Given a unit weighting function, *Gauss-Legendre points* (which we simply call *Gauss points* in this document for brevity) are parametric coordinates chosen so that quadrature integration will result in the highest possible accuracy with the fewest number of function evaluations. These points are generally all interior to a finite element (with exceptions such as Gauss-Lobatto points). Because these points are interior to a single finite element, they may be stored as element variables in an Exodus II file.

To reconstruct the field at some arbitrary (r,s,t) in the domain of a finite element, one must evaluate

$$\sigma_x(r,s,t) = \sum_i \sum_j \sum_k \sigma_x^{i,j,k} \Phi_{i,j,k}(r,s,t)$$

where $\sigma_x^{i,j,k}$ is the value of σ_x at Gauss point (i,j,k) and $\Phi_{i,j,k}(r,s,t)$ is the corresponding shape function evaluated at the desired (r,s,t). Note that the shape functions are not the same shape functions used to evaluate non-integral fields such as deflection — they are shape functions associated with the Gauss points. Although we can recover the stress and strain fields from the calculated deflection field, values computed at Gauss points can be more accurate[CMP89]. This is especially true for elements with non-planar faces such as those of the quadratic "Serendipity" element `HEX20`.

1.2 Naming Convention

Each Gauss point has a unique element variable name in the Exodus II file. This name can be decomposed into three parts: the head, the thorax, and the abdomen[1]. The head of a variable name identifies the scalar field defined by the Gauss point values. In this document, we give detailed suggestions for stress and strain in the case of tetrahedral and hexahedral elements, from which extrapolations to other element types can easily be devised. The thorax identifies the element type and the fact that the field is a Gauss point. Finally, the abdomen is a 3-digit label that specifies exactly which Gauss point the element variable stores. The naming scheme can accommodate up to 10 Gauss points along any coordinate axis, for a total of 1000 Gauss points per hexahedron or 220 Gauss points per tetrahedron. Although we provide specific name prefixes for stress and strain, any variable names with the correct thorax and abdomen will be properly handled by ParaView[2] and Ensight[3]. We have carefully chosen the convention for Gauss point labels so that the number of points along each coordinate axis can be determined without any additional information in the Exodus II file.

[1] After the three-part body segments of insects.
[2] http://www.paraview.org/
[3] http://www.ceintl.com/

2 Hexahedral elements

Hexahedral elements have three independent coordinate axes with Gauss points logically arranged in a unit cube.

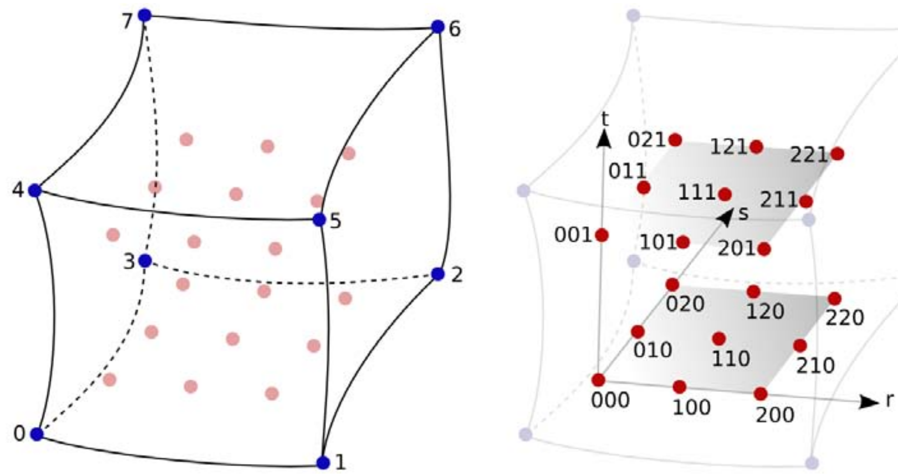

Figure 1. Naming convention for Gauss points of a hexahedron.

Figure 1 shows labels for an example hexahedron with three Gauss points along the r and s axes and 2 Gauss points along the t axis. Each label consists of three digits: i, j, and k. The first (i) corresponds to the location of the Gauss point along the first parametric axis, r. Similarly, j corresponds to s and k to t. A different number of Gauss points is supported for each coordinate axis. The three-digit label for each Gauss point is appended to the variable name to generate a unique storage name for each Gauss-point+variable combination.

Table 1 provides a list of variable names. As an example, consider the x-axis normal strain evaluated at the Gauss point nearest the initial corner vertex. This field would be named `SIGMA_XX_HEX20_GP000`.

Table 1. Variable names for Gauss points of a hexahedron.

Description	Head	Thorax	Abdomen
σ_{xx}, x-axis normal stress	SIGMA_XX	_HEX20_GP	nnn
σ_{yy}, y-axis normal stress	SIGMA_YY	_HEX20_GP	nnn
σ_{zz}, z-axis normal stress	SIGMA_ZZ	_HEX20_GP	nnn
σ_{xy}, xy-plane shear stress	SIGMA_XY	_HEX20_GP	nnn
σ_{yz}, yz-plane shear stress	SIGMA_YZ	_HEX20_GP	nnn
σ_{zx}, zx-plane shear stress	SIGMA_ZX	_HEX20_GP	nnn
ε_{xx}, x-axis normal strain	EPS_XX	_HEX20_GP	nnn
ε_{yy}, y-axis normal strain	EPS_YY	_HEX20_GP	nnn
ε_{zz}, z-axis normal strain	EPS_ZZ	_HEX20_GP	nnn
ε_{xy}, xy-plane shear strain	EPS_XY	_HEX20_GP	nnn
ε_{yz}, yz-plane shear strain	EPS_YZ	_HEX20_GP	nnn
ε_{zx}, zx-plane shear strain	EPS_ZX	_HEX20_GP	nnn

3 Tetrahedral elements

Tetrahedral elements have three independent coordinate axes with Gauss points logically arranged uniformly within a unit regular tetrahedron.

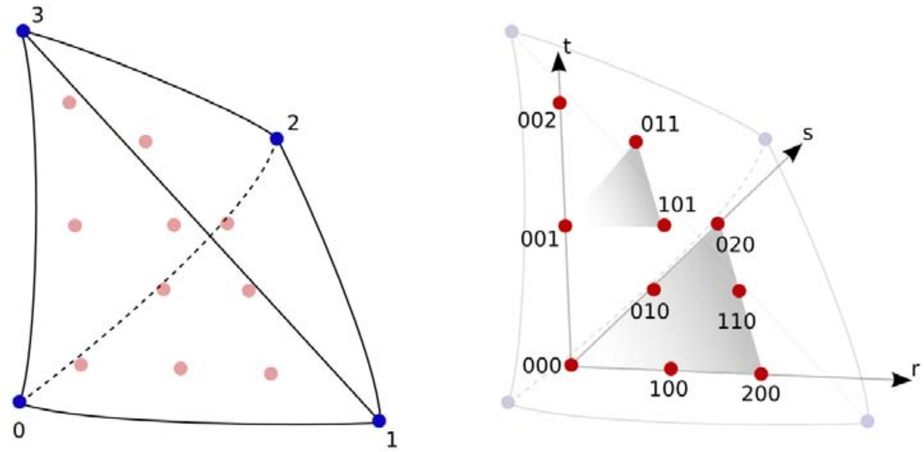

Figure 2. Naming convention for Gauss points of a tetrahedron.

Figure 2 shows labels for an example tetrahedron with three Gauss points along the r, s, and t axes. Again, we use i to denote the first digit of a label, j for the second, and k for the third. For a tetrahedron, we require $i+j+k \leq p$, where p is the maximum number of Gauss points along any axis. A different number of Gauss points is *not* currently supported for each coordinate axis. The three-digit label for each Gauss point is appended to the variable name to generate a unique storage name for each Gauss-point+variable combination.

Table 2 provides a list of variable names. As an example, consider the x-axis normal strain evaluated at the Gauss point nearest the initial corner vertex. This field would be named `SIGMA_XX_TET10_GP000`. For $p = 2$, note that `SIGMA_XX_TET10_GP210` does not exist.

Table 2. Variable names for Gauss points of a tetrahedron.

Description	Head	Thorax	Abdomen
σ_{xx}, x-axis normal stress	SIGMA_XX	_TET10_GP	nnn
σ_{yy}, y-axis normal stress	SIGMA_YY	_TET10_GP	nnn
σ_{zz}, z-axis normal stress	SIGMA_ZZ	_TET10_GP	nnn
σ_{xy}, xy-plane shear stress	SIGMA_XY	_TET10_GP	nnn
σ_{yz}, yz-plane shear stress	SIGMA_YZ	_TET10_GP	nnn
σ_{zx}, zx-plane shear stress	SIGMA_ZX	_TET10_GP	nnn
ε_{xx}, x-axis normal strain	EPS_XX	_TET10_GP	nnn
ε_{yy}, y-axis normal strain	EPS_YY	_TET10_GP	nnn
ε_{zz}, z-axis normal strain	EPS_ZZ	_TET10_GP	nnn
ε_{xy}, xy-plane shear strain	EPS_XY	_TET10_GP	nnn
ε_{yz}, yz-plane shear strain	EPS_YZ	_TET10_GP	nnn
ε_{zx}, zx-plane shear strain	EPS_ZX	_TET10_GP	nnn

4 Perspectives

Although we do not specify names for other than `HEX20` and `TET10` elements, it should be clear how to extend the specification.

ParaView and Ensight differ in how the stored data is interpreted. Because Ensight provides only linear and serendipity interpolation, the full interpolant the Gauss points provide cannot be used. Instead, values at Gauss points will be extrapolated to corner nodes of each cell and then averaged with other corner node values computed from Gauss points of elements that share corners. This provides a trilinear, C^0-continuous approximation of the triquadratic, discontinuous interpolation. ParaView provides the same functionality for ease of use, but also provides exact interpolation using the shape functions provided by the application, *e.g.*, Salinas. The user interface for choosing the interpolation type has yet to be decided but will either be a checkbutton in the Exodus II reader or a filter for "promoting" a mesh to a higher-order representation.

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