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EXODUS: A Finite Element Data Model

Gregory D. Sjaardema
Larry A. Schoof
Victor R. Yarberry
Computational Mechanics and Visualization Department
Sandia National Laboratories
Albuquerque, NM 87185

Abstract

EXODUS is a model developed to store and retrieve data for finite element analyses. It is used for preprocessing (problem definition), postprocessing (results visualization), as well as code to code data transfer. An EXODUS data file is a random access, machine independent, binary file that is written and read via C, C++, or Fortran library routines which comprise the Application Programming Interface (API).

See also the doxygen-generated documentation at https://sandialabs.github.io/seacas-docs/html/index.html

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Chapter 1

Introduction

EXODUS is the successor of the widely used finite element (FE) data file format EXODUS [1] (henceforth referred to as EXODUS I) developed by Mills-Curran and Flanagan. It continues the concept of a common database for multiple application codes (mesh generators, analysis codes, visualization software, etc.) rather than code-specific utilities, affording flexibility and robustness for both the application code developer and application code user. By using the EXODUS data model, a user inherits the flexibility of using a large array of application codes (including vendor-supplied codes) which access this common data file directly or via translators.

The uses of the EXODUS data model include the following:

- problem definition – mesh generation, specification of locations of boundary conditions and load application, specification of material types.
- simulation – model input and results output.
- visualization – model verification, results postprocessing, data interrogation, and analysis tracking.

1.1 License and Availability

The EXODUS library is licensed under the BSD open source license.

The EXODUS library source code is available on GitHub https://github.com/sandialabs/seacas.git

For bug reports, documentation errors, and enhancement suggestions, contact:

- Gregory D. Sjaardema
- EMAIL: mailto:gdsjaar@sandia.gov
- EMAIL: mailto:gsjaardema@gmail.com

Chapter 2

Changes Since First Printing

There have been several changes to the EXODUS API in the years since the original EXODUS report was published. The main changes are:

- Addition of Coordinate Frames.
- Addition of node set and side set results variables.
- Addition of element block, node set, side set, element map, and node map names.
- Support for very large model.
- Efficient replication of the model definition "genesis" portion of the database.
- Multiple, optional named node and element maps which can be used for any purpose.
- Support for "meshes" with no node or elements; or nodes, but no elements.

There have also been some functions added to make it easier to write an EXODUS database efficiently. These include:

- API function to write concatenated element block information, and
- API function to defined all results data with one function call.

Chapter 3

Development of EXODUS

The evolution of the EXODUS() data model has been steered by FE application code developers who desire the advantages of a common data format. The EXODUS model has been designed to overcome deficiencies in the EXODUS I file format and meet the following functional requirements as specified by these developers:

- random read/write access.
- application programming interface (API) – provide routines callable from FORTRAN, C, and C++ application codes.
- extensible – allow new data objects to be added without modifying the application programs that use the file format.
- machine independent – data should be independent of the machine which generated it.
- real time access during analysis – allow access to the data in a file while the file is being created.

To address these requirements, the public domain database library netCDF [3] was selected to handle the low-level data storage. The EXODUS library functions provide the mapping between FE data objects and netCDF dimensions, attributes, and variables. (These mappings are documented in Appendix A.) Thus, the code developer interacts with the data model using the vocabulary of an FE analyst (element connectivity, nodal coordinates, etc.) and is relieved of the details of the data access mechanism. To provide machine independency, the netCDF library stores data in eXternal Data Representation (XDR) [4] format.

Because an EXODUS file is a netCDF file, an application program can access data via the EXODUS API or via netCDF API function calls directly. Although the latter two methods require more in-depth understanding of netCDF, this capability is a powerful feature that allows the development of auxiliary libraries of special purpose functions not offered in the standard EXODUS() library. For example, if an application required access to the coordinates of a single node (the standard library function returns the coordinates for all of the nodes in the model), a simple function could be written that calls netCDF routines directly to read the data of interest.

Chapter 4

Description of Data Objects

entity	block	set	map
node		nodeset	nodemap
edge	edgeblock	edgeset	edgemap
face	faceblock	faceset	facemap
element	element block	elementset	elementmap

The data in EXODUS files can be divided into three primary categories: initialization data, model data, and results data.

Initialization data includes sizing parameters (number of nodes, number of elements, etc.), optional quality assurance information (names of codes that have operated on the data), and optional informational text.

The model is described by data which are static (do not change through time). This data includes nodal coordinates, element connectivity (node lists for each element), element attributes, and node sets and side sets (used to aid in applying loading conditions and boundary constraints).

The results are optional and include five types of variables – nodal, element, nodeset, sideset, and global – each of which is stored through time. Nodal results are output (at each time step) for all the nodes in the model. An example of a nodal variable is displacement in the X direction. Element, nodeset, and sideset results are output (at each time step) for all entities (elements, nodes, sides) in one or more entity block. For example, stress may be an element variable. Another use of element variables is to record element status (a binary flag indicating whether each element is "alive" or "dead") through time. Global results are output (at each time step) for a single element or node, or for a single property. Linear momentum of a structure and the acceleration at a particular point are both examples of global variables. Although these examples correspond to typical FE applications, the data format is flexible enough to accommodate a spectrum of uses.

A few conventions and limitations must be cited:

- There are no restrictions on the frequency of results output except that the time value associated with each successive time step must increase monotonically.
- To output results at different frequencies (i.e., variable A at every simulation time step, variable B at every other time step) multiple EXODUS files must be used.
- There are no limits to the number of each type of results, but once declared, the number cannot change.

- If the mesh geometry changes in time (i.e., number of nodes increases, connectivity changes), the new geometry must be output to a new EXODUS file.

The following sections describe the data objects that can be stored in an EXODUS file. API functions that read / write the particular objects are included for reference. API routines for the C binding are in lower case. Refer to Section 4 on page 21 for a detailed description of each API function.

4.1 Global Parameters

API Functions: ex_put_init, ex_get_init

Every EXODUS file is initialized with the following parameters:

- Title – data file title of length `MAX_LINE_LENGTH`. Refer to discussion below for definition of `MAX_LINE_LENGTH`.
- Number of nodes – the total number of nodes in the model.
- Problem dimensionality – the number of spatial coordinates per node (1, 2, or 3).
- Number of elements – the total number of elements of all types in the file.
- Number of element blocks – within the EXODUS data model, elements are grouped together into blocks. Refer to Section 3.8 on page 8 for a description of element blocks.
- Number of node sets – node sets are a convenient method for referring to groups of nodes. Refer to Section 3.9 on page 11 for a description of node sets.
- Number of side sets – side sets are used to identify elements (and their sides) for specific purposes. Refer to Section 3.11 on page 12 for a description of side sets.
- Database version number – the version of the data objects stored in the file. This document describes database version is 4.72.
- API version number – the version of the EXODUS library functions which stored the data in the file. The API version can change without changing the database version and vice versa. This document describes API version 4.72.
- I/O word size – indicates the precision of the floating point data stored in the file. Currently, four- or eight-byte floating point numbers are supported. It is not necessary that an application code be written to handle the same precision as the data stored in the file. If required, the routines in the EXODUS library perform automatic conversion between four- and eight-byte numbers.
- Length of character strings – all character data stored in an EXODUS file is either of length `MAX_STR_LENGTH` or `MAX_LINE_LENGTH`. These two constants are defined in the file ***exodusII.h***. Current values are 32 and 80, respectively.
- Length of character lines – see description above for length of character strings.

4.2 Quality Assurance Data

API Functions: ex_put_qa, ex_get_qa

Quality assurance (QA) data is optional information that can be included to indicate which application codes have operated on the data in the file. Any number of QA records can be included, with each record containing four character strings of length `MAX_STR_LENGTH`. The four character strings are the following (in order):

Code name indicates the application code that has operated on the EXODUS file.

Code QA descriptor provides a location for a version identifier of the application code.

Date the date on which the application code was executed; should be in the format 20080331.

Time the 24-hour time at which the application code was executed; should be in the format hours:minutes:seconds, such as 16:30:15.

4.3 Information Data

API Functions: ex_put_info, ex_get_info

This is for storage of optional supplementary text. Each text record is of length `MAX_LINE_LENGTH`; there is no limit to the number of text records.

4.4 Nodal Coordinates

API Functions: ex_put_coord, ex_get_coord

The nodal coordinates are the floating point spatial coordinates of all the nodes in the model. The number of nodes and the problem dimension define the length of this array. The node index cycles faster than the dimension index, thus the X coordinates for all the nodes is written before any Y coordinate data are written. Internal node numbers (beginning with 1) are implied from a nodes's place in the nodal coordinates record. See Section 4.5 for a discussion of internal node numbers.

4.4.1 Coordinate Names

API Functions: ex_put_coord_names, ex_get_coord_names

The coordinate names are character strings of length `MAX_STR_LENGTH` which name the spatial coordinates. There is one string for each dimension in the model, thus there are one to three strings.

4.5 Node Number Map

API Functions: ex_put_node_num_map, ex_get_node_num_map

Within the data model, internal node IDs are indices into the nodal coordinate array and internal element IDs are indices into the element connectivity array. Thus, internal node and element numbers (IDs) are contiguous (i.e., 1...number˙of˙nodes and 1...number˙of˙elements, respectively). Optional node and element number maps can be stored to relate user-defined node and element IDs to these internal node and element numbers. The length of these maps are number˙of˙nodes and number˙of˙elements, respectively. As an example, suppose a database contains exactly one QUAD element with four nodes. The user desires the element ID to be 100 and the node IDs to be 10, 20, 30, and 40 as shown in Figure 4.1.

Node IDs	Node coordinates	
10	0.0	0.0
20	1.0	0.0
30	1.0	1.0
40	0.0	1.0

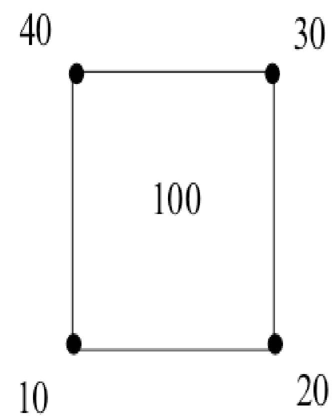


Figure 4.1: User-defined Node and Element IDs.

The internal data structures representing the above model would be the following:

- nodal coordinate array: (0.0, 1.0, 1.0, 0.0, 0.0, 0.0, 1.0, 1.0)
- connectivity array: (1, 2, 3, 4)
- node number map: (10, 20, 30, 40)
- element number map: (100)

Internal (contiguously numbered) node and element IDs must be used for all data structures that contain node or element numbers (IDs), including node set node lists, side set element lists, and element connectivity. Additionally, to inquire the value(s) of node or element results variables, an application code must pass the internal node or element number for the node or element of interest.

4.6 Element Number Map

API Functions: ex_put_elem_num_map, ex_get_elem_num_map

Refer to Section 3.5 for a discussion of the optional element number map.

4.7 Optimized Element Order Map

API Functions: ex_put_map, ex_get_map

The optional element order map defines the element order in which a solver (e.g., a wavefront solver) should process the elements. For example, the first entry is the number of the element which should be processed first by the solver. The length of this map is the total number of elements in the model.

4.8 Element Blocks

For efficient storage and to minimize I/O, elements are grouped into element blocks. Within an element block, all elements are of the same type (basic geometry and number of nodes). This definition does not preclude multiple element blocks containing the same element type (i.e., "QUAD" elements may be in more than one element block); only that each element block may contain only one element type.

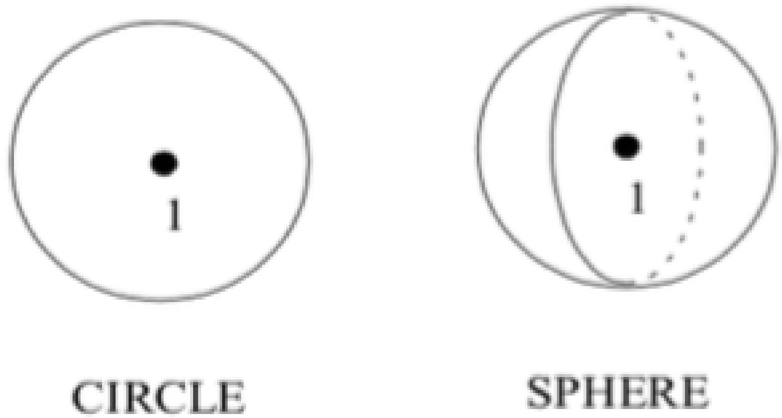
The internal number of an element numbering is defined implicitly by the order in which it appears in the file. Elements are numbered internally (beginning with 1) consecutively across all element blocks. See Section 4.6 for a discussion of internal element numbering.

4.8.1 Element Block Parameters

API Functions: ex_put_elem_block, ex_get_elem_block, ex_get_elem_blk_ids

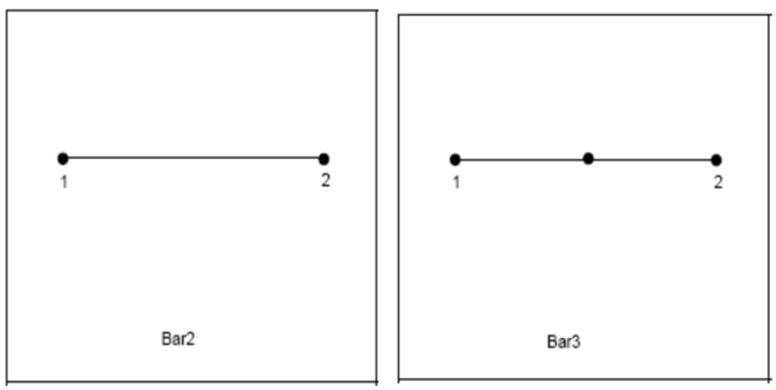
The following parameters are defined for each element block:

- element block ID – an arbitrary, unique, positive integer which identifies the particular element block. This ID is used as a "handle" into the database that allows users to specify a group of elements to the application code without having to know the order in which element blocks are stored in the file.
- element type Element type – a character string of length `MAX_STR_LENGTH` to distinguish element types. All elements within the element block are of this type. Refer to Table 4.1 on page 22 for a list of names that are currently accepted. It should be noted that the EXODUS library routines do not verify element type names against a standard list; the interpretation of the element type is left to the application codes which read or write the data. In general, the first three characters uniquely identify the element type. Application codes can append characters to the element type string (up to the maximum length allowed) to further classify the element for specific purposes.
- Number of elements – the number of elements in the element block.
- Nodes per element – the number of nodes per element for the element block.
- Number of attributes – the number of attributes per element in the element block. See below for a discussion of element attributes.



(a) Circle (b) Sphere

Figure 4.2: Node Ordering for Circle and Sphere Elements



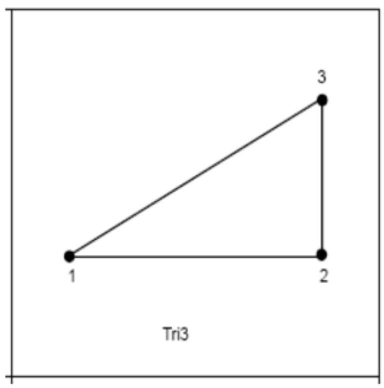
(a) Bar2 (b) Bar3

Figure 4.3: Node Ordering for Bar/Truss/Beam Elements

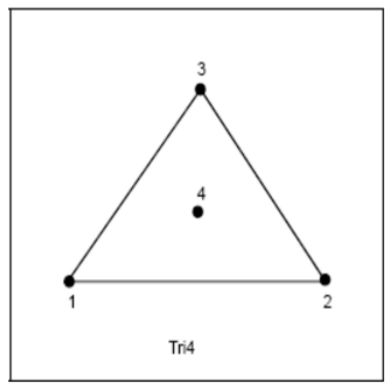
4.8.2 Element Connectivity

API Functions: ex_put_elem_conn, ex_get_elem_conn

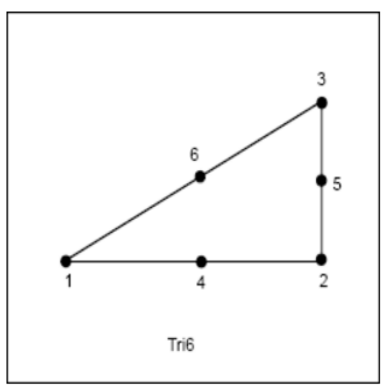
The element connectivity contains the list of nodes (internal node IDs; see Section 4.6 for a discussion of node IDs) which define each element in the element block. The length of this list is the product of the number of elements and the number of nodes per element as specified in the element block parameters. The node index cycles faster than the element index. Node ordering follows the conventions illustrated in Figures 4.2 through 4.14. The node ordering conventions follow the element topology used in `PATRAN` [?]. Thus, for higher-order elements than those illustrated, use the ordering prescribed in the `PATRAN` User Manual `http://web.mscsoftware.com/training_videos/patran/reverb3/index.html#page/Finite%2520Element%2520Modeling/elem_lib_topics.16.1.html#ww33606`. For elements of type CIRCLE or SPHERE, the topology is one node at the center of the circle or sphere element.



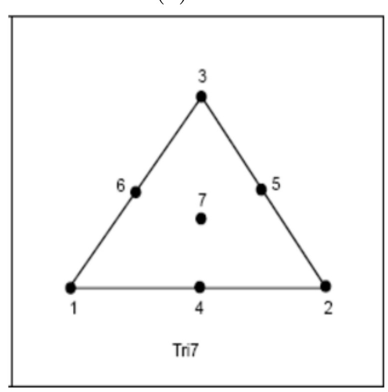
(a) Tri3



(b) Tri4

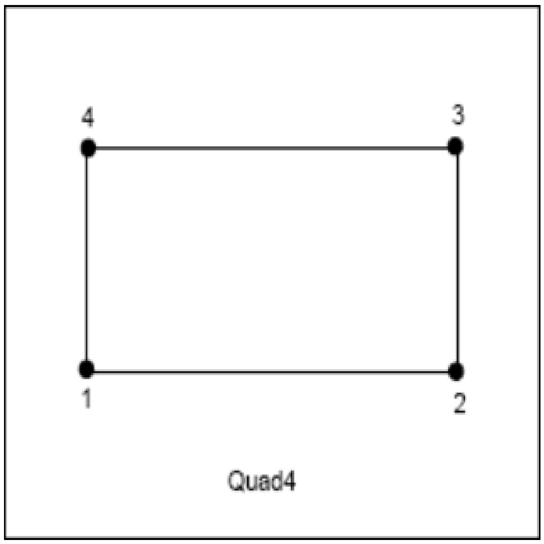


(c) Tri6

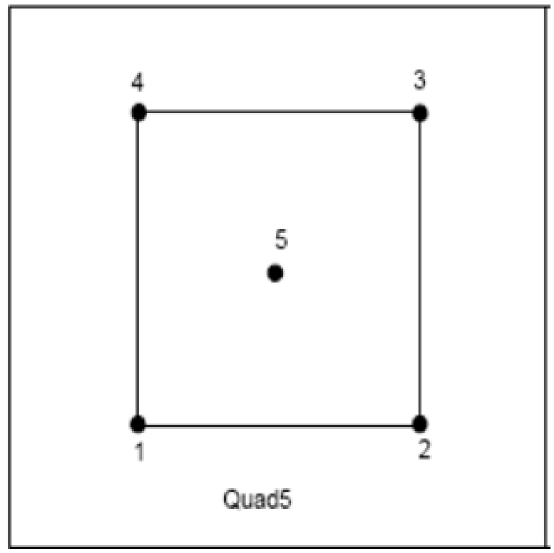


(d) Tri7

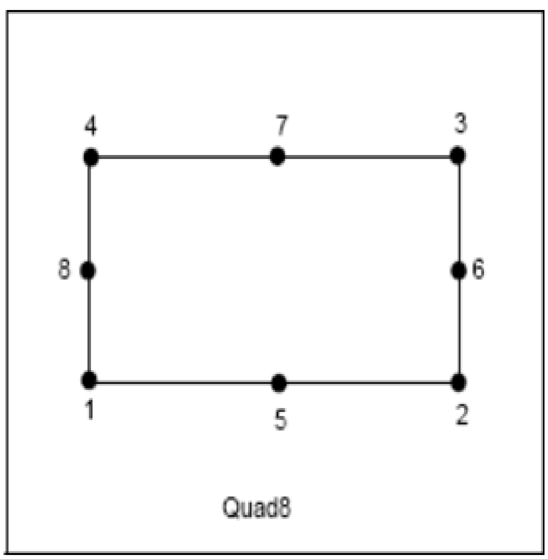
Figure 4.4: Node Ordering for Triangular Elements.



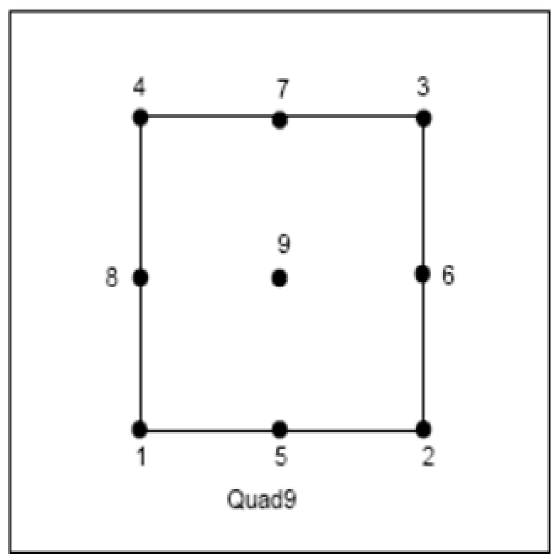
(a) Quad4



(b) Quad5

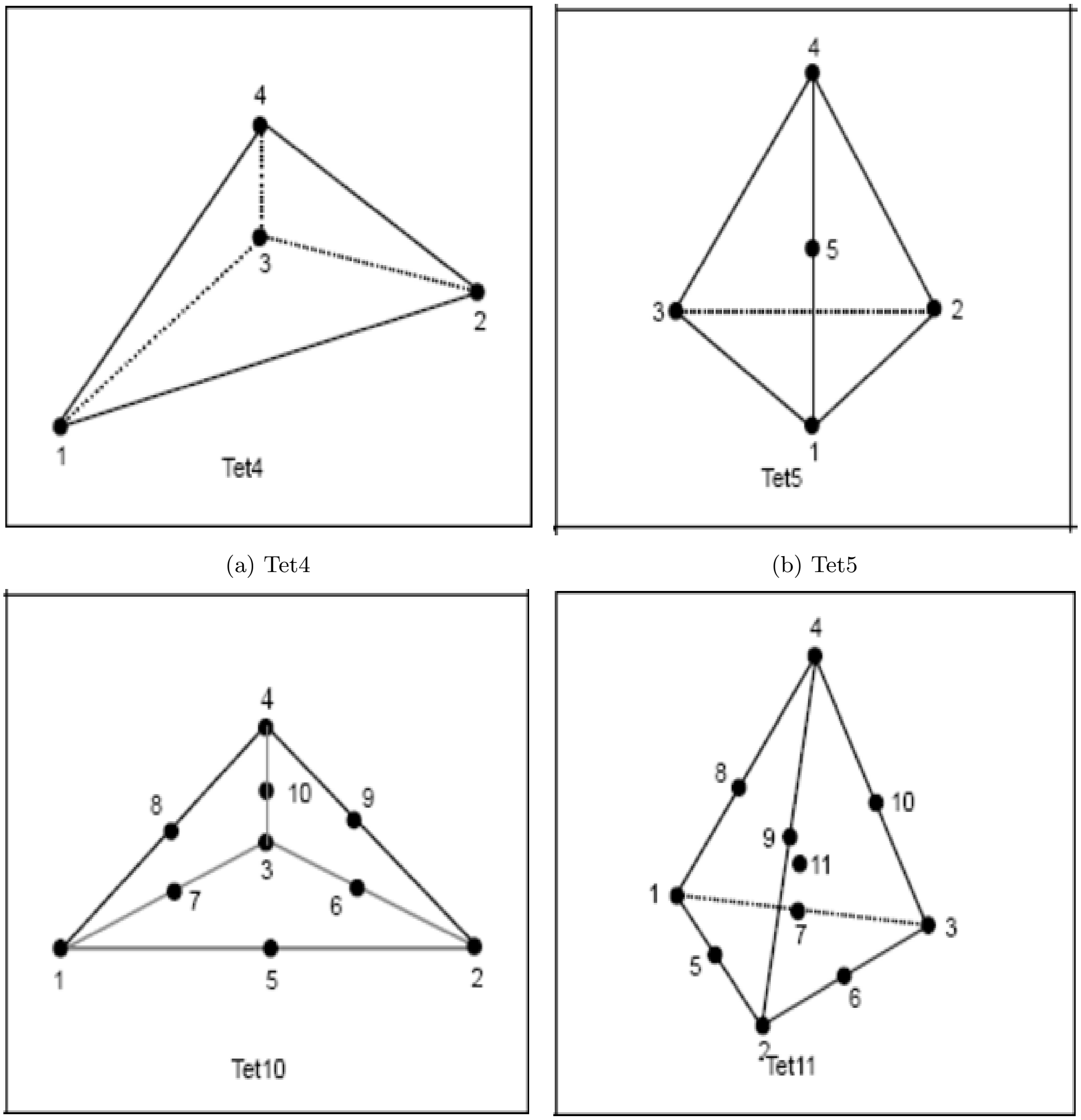


(c) Quad8



(d) Quad9

Figure 4.5: Node Ordering for Quadrilateral Elements.



(a) Tet4 (b) Tet5

(c) Tet10 (d) Tet11

Figure 4.6: Node Ordering for Tetrahedral Elements.

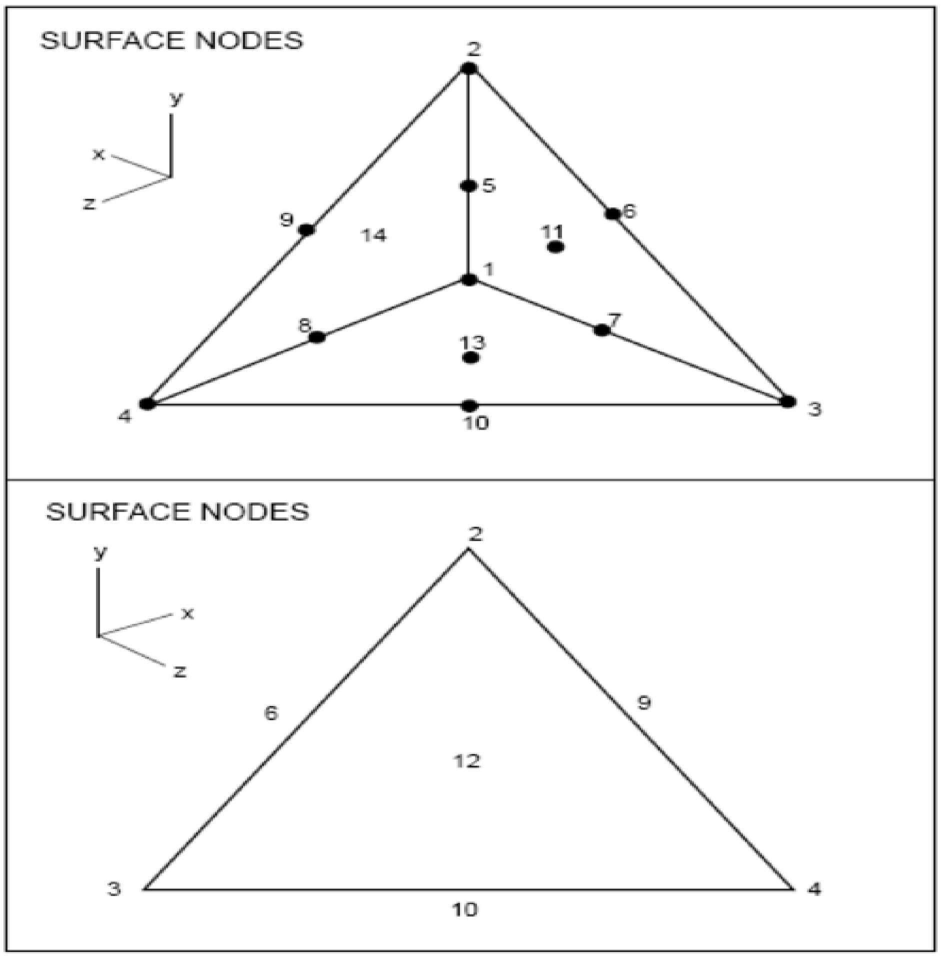


Figure 4.7: Node Ordering for Tetrahedral Tet14 Element.

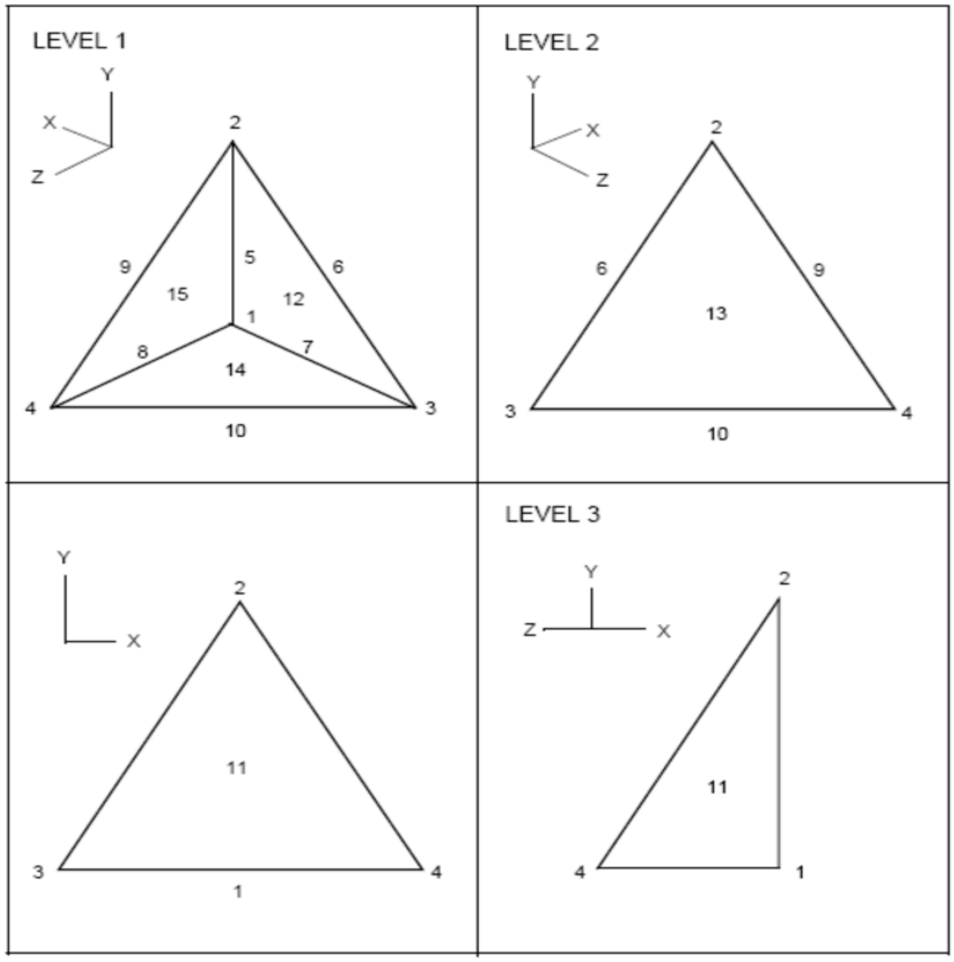


Figure 4.8: Node Ordering for Tetrahedral Tet15 Element.

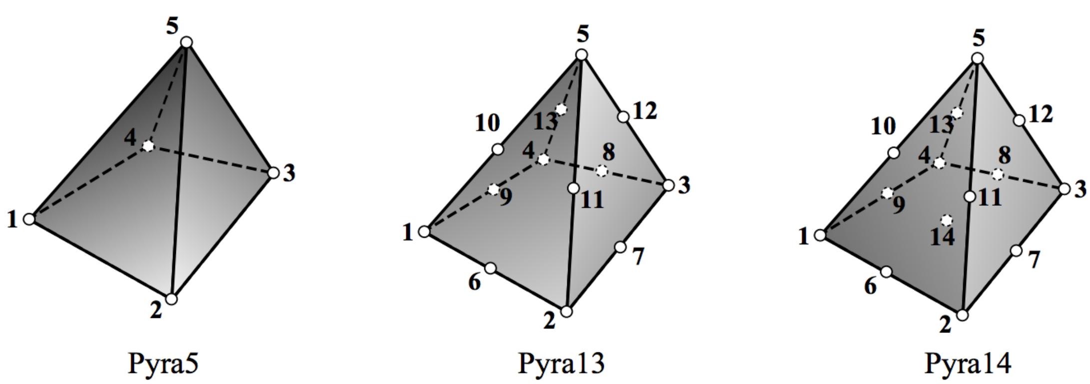
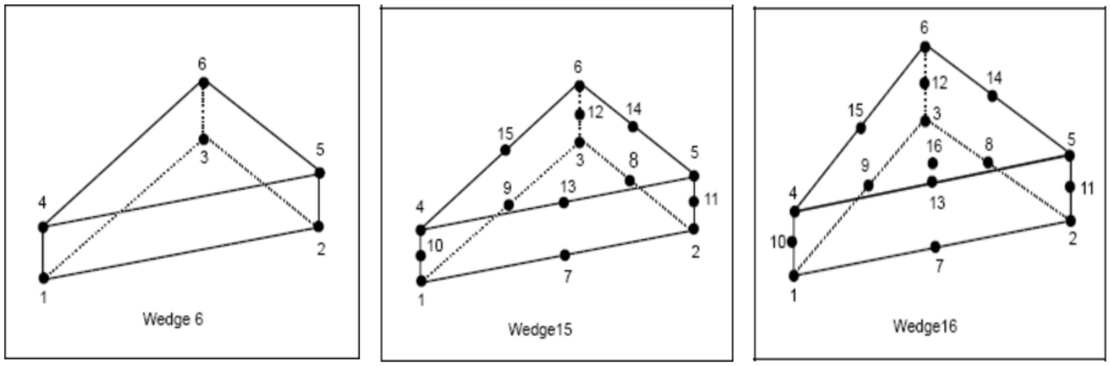


Figure 4.9: Node Ordering for Pyramid Elements (pyramid5, pyramid13, pyramid14).



(a) Wedge6 (b) Wedge15 (c) Wedge16

Figure 4.10: Node Ordering for Wedge Elements.

4.8.3 Element Attributes

API Functions: ex_put_elem_attr, ex_get_elem_attr

Element attributes are optional floating point numbers that can be assigned to each element. Every element in an element block must have the same number of attributes (as specified in the element block parameters) but the attributes may vary among elements within the block. The length of the attributes array is thus the product of the number of attributes per element and the number of elements in the element block. Table 4.1 lists the standard attributes for the given element types.

Element Type	Attributes
CIRCLE	R
SPHERE	R
TRUSS	A
BEAM	2D: A, I, J 3D: A, I_1, I_2, J, V_1, V_2, V_3
TRIANGLE	
QUAD	
SHELL	T
TETRA	
PYRAMID	
WEDGE	
HEX	

Table 4.1: Standard Element Types and Attributes

4.9 Node Sets

Node sets provide a means to reference a group of nodes with a single ID. Node sets may be used to specify load or boundary conditions, or to identify nodes for a special output request. A particular

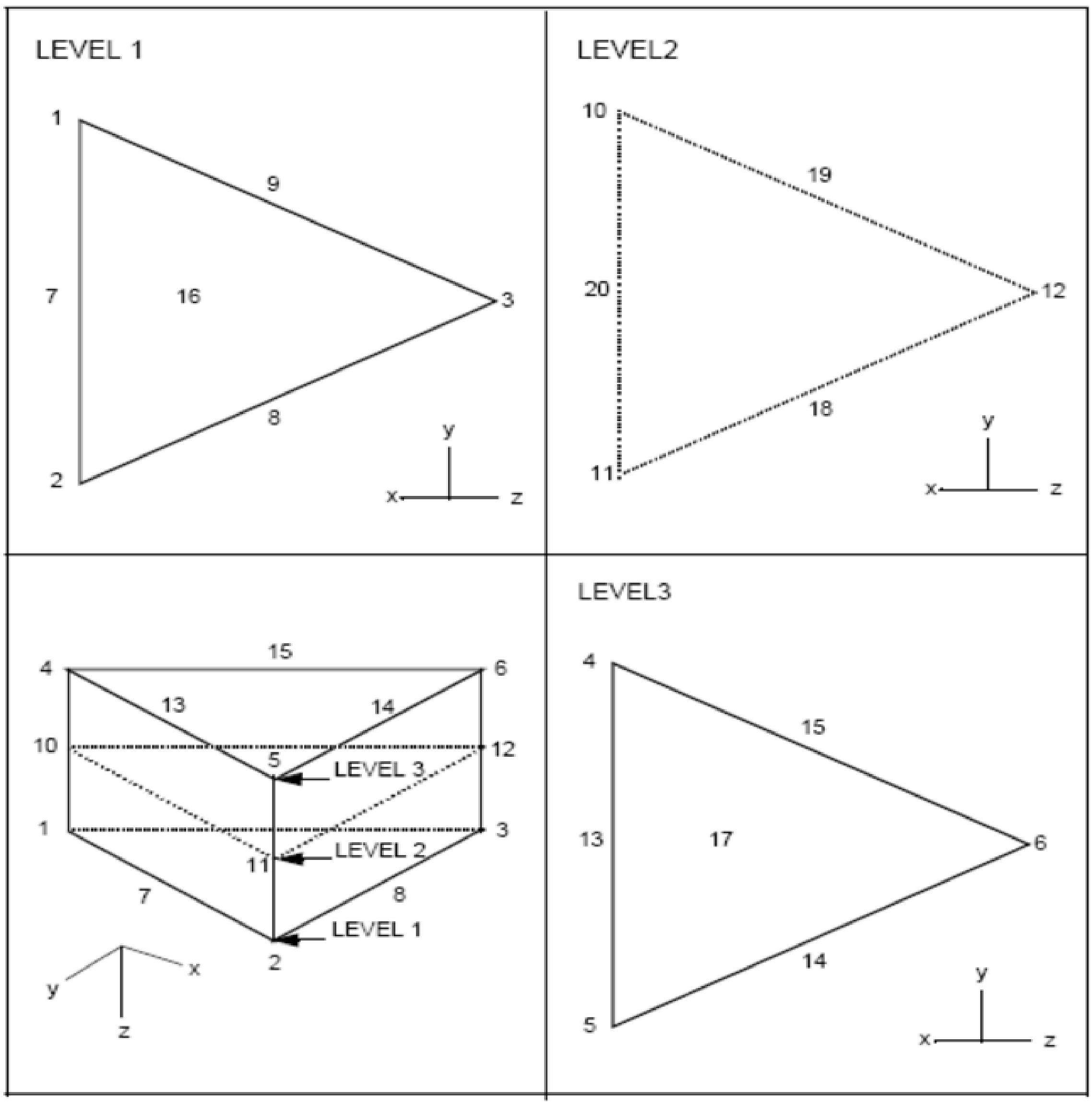


Figure 4.11: Node Ordering for Wedge Elements (Wedge20).

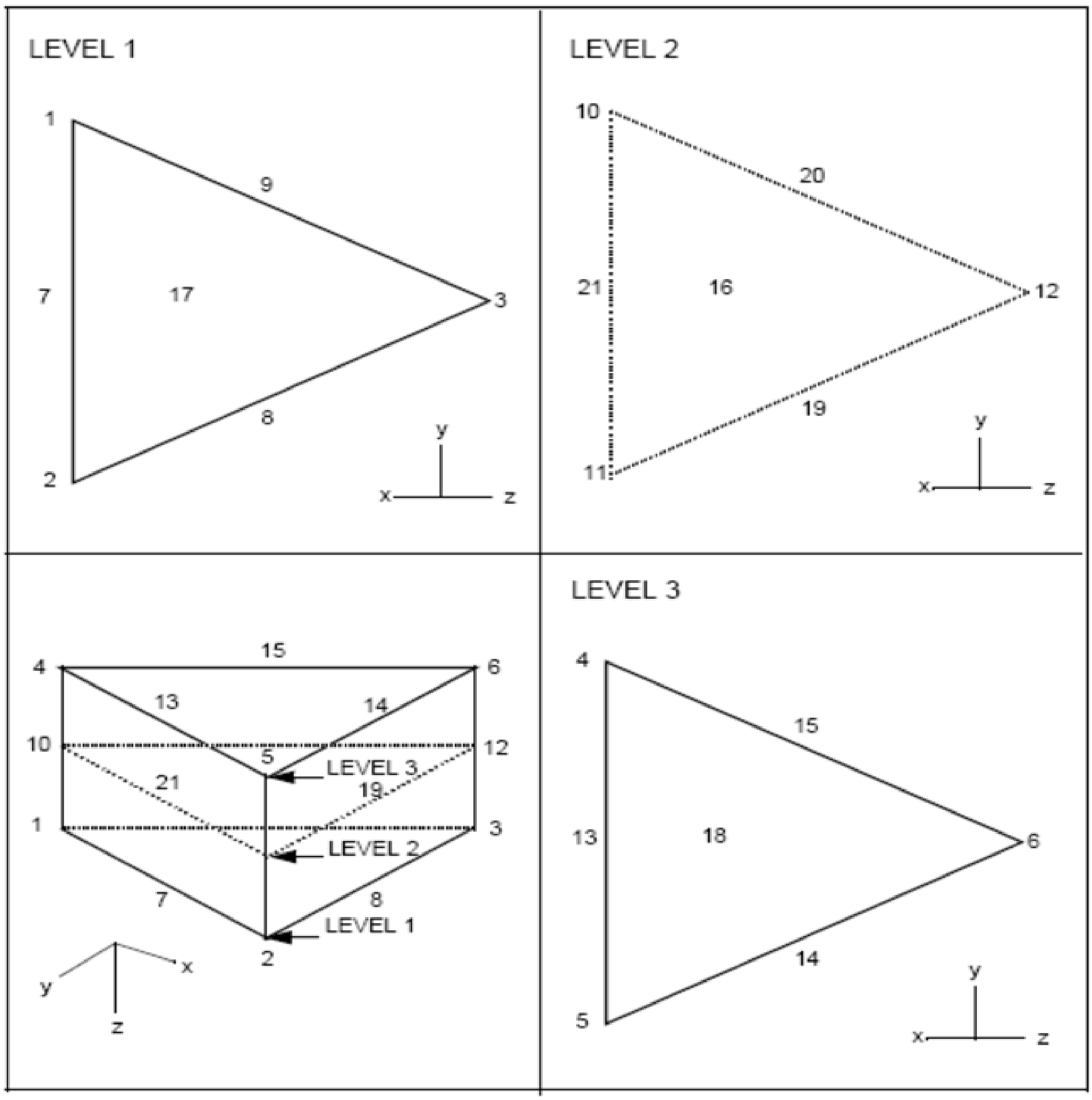
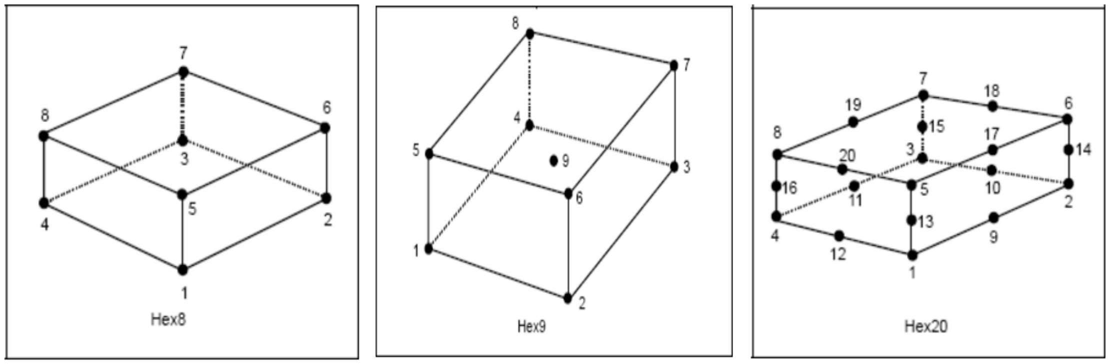


Figure 4.12: Node Ordering for Wedge Elements (Wedge21).



(a) Hex8 (b) Hex9 (c) Hex20

Figure 4.13: Node Ordering for Hexahedral Elements.

node may appear in any number of node sets, but may be in a single node set only once. (This restriction is not checked by EXODUS routines.) Node sets may be accessed individually (using node set parameters, node set node list, and node set distribution factors) or in a concatenated format (described in Section 3.10 on page 11). The node sets data are stored identically in the data file regardless of which method (individual or concatenated) was used to output them.

4.9.1 Node Set Parameters

API Functions: ex_put_node_set_param, ex_get_node_set_param, ex_get_node_set_ids *API Functions:* ex_put_set_param, ex_get_set_param, ex_get_set_ids

The following parameters define each node set:

- node set ID – a unique positive integer that identifies the node set.
- Number of nodes – the number of nodes in the node set.
- Number of node set distribution factors – this should be zero if there are no distribution factors for the node set. If there are any distribution factors, this number must equal the number of nodes in the node set since the factors are assigned at each node. Refer to the discussion of distribution factors below.

4.9.2 Node Set Node List

API Functions: ex_put_node_set, ex_get_node_set

This is an integer list of all the nodes in the node set. Internal node IDs (see Section 4.6) must be used in this list.

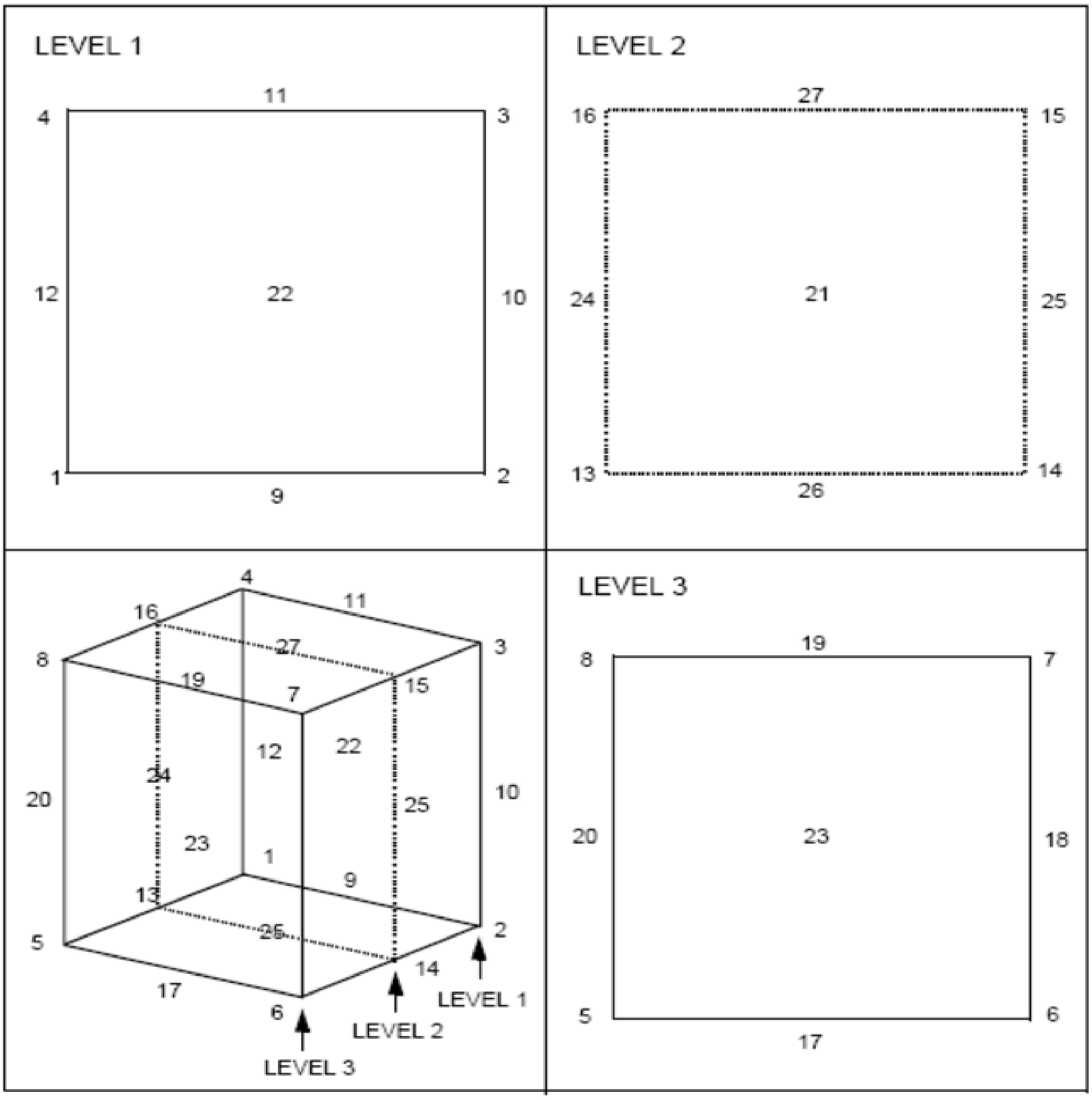


Figure 4.14: Node Ordering for Hexahedral Elements (Hex27).

4.9.3 Node Set Distribution Factors

API Functions: ex_put_node_set_dist_fact , ex_get_node_set_dist_fact

This is an optional list of floating point factors associated with the nodes in a node set. These data may be used as multipliers on applied loads. If distribution factors are stored, each entry in this list is associated with the corresponding entry in the node set node list.

4.10 Concatenated Node Sets

API Functions: ex_put_concat_node_sets, ex_get_concat_node_sets

Concatenated node sets provide a means of writing/reading all node sets with one function call. This is more efficient because it avoids some I/O overhead, particularly when considering the intricacies of the `NetCDF` library. (Refer to Appendix A for a discussion of efficiency concerns.) This is accomplished with the following lists:

- Node sets IDs – list (of length number of node sets) of unique integer node set ID's. The i^{th} entry in this list specifies the ID of the i^{th} node set.
- Node sets node counts – list (of length number of node sets) of counts of nodes for each node set. Thus, the i^{th} entry in this list specifies the number of nodes in the i^{th} node set.
- Node sets distribution factors counts – list (of length number of node sets) of counts of distribution factors for each node set. The i^{th} entry in this list specifies the number of distribution factors in the i^{th} node set.
- Node sets node pointers – list (of length number of node sets) of indices which are pointers into the node sets node list locating the first node of each node set. The i^{th} entry in this list is an index in the node sets node list where the first node of the i^{th} node set can be located.
- Node sets distribution factors pointers – list (of length number of node sets) of indices which are pointers into the node sets distribution factors list locating the first factor of each node set. The i^{th} entry in this list is an index in the node sets distribution factors list where the first factor of the i^{th} node set can be located.
- Node sets node list – concatenated integer list of the nodes in all the node sets. Internal node IDs (see Section 4.6) must be used in this list. The node sets node pointers and node sets node counts are used to find the first node and the number of nodes in a particular node set.
- Node sets distribution factors list – concatenated list of the (floating point) distribution factors in all the node sets. The node sets distribution factors pointers and node sets distribution factors counts are used to find the first factor and the number of factors in a particular node set.

To clarify the use of these lists, refer to the coding examples in Section 4.2.25 and Section 4.2.26.

4.11 Side Sets

Side sets provide a second means of applying load and boundary conditions to a model. Unlike node sets, side sets are related to specified sides of elements rather than simply a list of nodes. For example, a pressure load must be associated with an element edge (in 2-d) or face (in 3-d) in order to apply it properly. Each side in a side set is defined by an element number and a local edge (for 2-d elements) or face (for 3-d elements) number. The local number of the edge or face of interest must conform to the conventions as illustrated in Figure 4.15.

In this figure, side set side numbers are enclosed in boxes; only the essential node numbers to describe the element topology are shown. A side set may contain sides of differing types of elements that are contained in different element blocks. For instance, a single side set may contain faces of WEDGE elements, HEX elements, and TETRA elements.

4.11.1 Side Set Parameters

API Functions: ex_put_side_set_param, ex_get_side_set_param, ex_get_side_set_ids

The following parameters define each side set:

- side set ID – a unique positive integer that identifies the side set.
- Number of sides – the number of sides in the side set.
- Number of side set distribution factors – this should be zero if there are no distribution factors for the side set. If there are any distribution factors, they are assigned at the nodes on the sides of the side set. Refer to the discussion of distribution factors below.

4.11.2 Side Set Element List

API Functions: ex_put_side_set , ex_get_side_set

This is an integer list of all the elements in the side set. Internal element IDs (see Section 4.6) must be used in this list.

4.11.3 Side Set Side List

API Functions: ex_put_side_set , ex_get_side_set

This is an integer list of all the sides in the side set. This list contains the local edge (for 2-d elements) or face (for 3-d elements) numbers following the conventions specified in Figure 5.

4.11.4 Side Set Node List

API Functions: ex_get_side_set_node_list

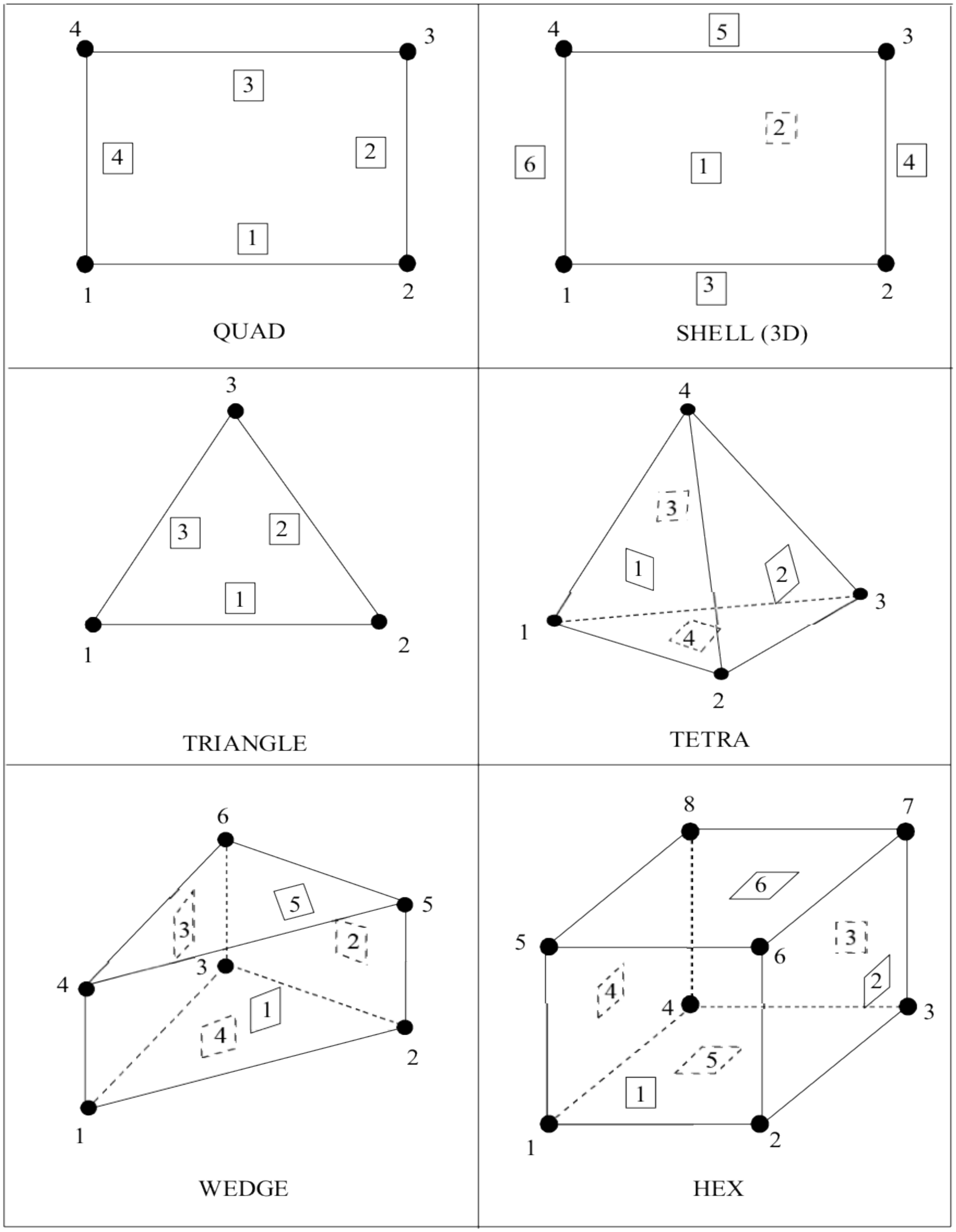


Figure 4.15: Side Set Side Numbering.

It is important to note that the nodes on a side set are not explicitly stored in the data file, but can be extracted from the element numbers in the side set element list, local side numbers in the side set side list, and the element connectivity array. The node IDs that are output are internal node numbers (see Section 4.5). They are extracted according to the following conventions:

1. All nodes for the first side (defined by the first element in the side set element list and the first side in the side set side list) are output before the nodes for the second side. There is no attempt to consolidate nodes; if a node is attached to four different faces, then the same node number will be output four times – once each time the node is encountered when progressing along the side list.
2. The nodes for a single face (or edge) are ordered to assist an application code in determining an "outward" direction. Thus, the node list for a face of a 3-d element proceeds around the face so that the outward normal follows the right-hand rule. The node list for an edge of a 2-d element proceeds such that if the right hand is placed in the plane of the element palm down, thumb extended with the index (and other fingers) pointing from one node to the next in the list, the thumb points to the inside of the element. This node ordering is detailed in Table 4.2 on page 31
3. The nodes required for a first-order element are output first, followed by the nodes of a higher ordered element. Table 4.2 lists the nodes for first-order elements. Refer to the node orderings shown in Figures 4.2 to 4.14 for the additional nodes on higher-order elements. If a face has a mid-face node, it is listed last following all mid-edge nodes. For example, the node ordering for side 1 of the `hex27` element is 1,2,6,5,9,14,17,13,26

4.11.5 Side Set Node Count List

API Functions: ex_get_side_set_node_list

The length of the side set node count list is the length of the side set element list. For each entry in the side set element list, there is an entry in the side set side list, designating a local side number. The corresponding entry in the side set node count list is the number of nodes which define the particular side. In conjunction with the side set node list, this node count array provides an unambiguous nodal description of the side set.

4.11.6 Side Set Distribution Factors

API Functions: ex_put_side_set_dist_fact , ex_get_side_set_dist_fact

This is an optional list of floating point factors associated with the nodes on a side set. These data may be used for uneven application of load or boundary conditions. Because distribution factors are assigned at the nodes, application codes that utilize these factors must read the side set node list. The distribution factors must be stored/accessed in the same order as the nodes in the side set node list; thus, the ordering conventions described above apply.

Element Type	Side #	Node Order		
QUAD	1	1, 2,	5	
(2D)	2	2, 3,	6	
	3	3, 4,	7	
	4	4, 1,	8	
SHELL	1	1, 2, 3, 4,	5, 6, 7, 8,	9
	2	1, 4, 3, 2,	8, 7, 6, 5,	9
(Edges)	3	1, 2,	5	
	4	2, 3,	6	
	5	3, 4,	7	
	6	4, 1,	8	
TRIANGLE	1	1, 2,	4	
(2D)	2	2, 3,	5	
	3	3, 1,	6	
TRIANGLE	1	1, 2, 3,	4, 5, 6	
(Shell)	2	1, 3, 2,	6, 5, 4	
	3	1, 2,	4	
	4	2, 3,	5	
	5	3, 1,	6	
TETRA	1	1, 2, 4,	5, 9, 8	
	2	2, 3, 4,	6, 10, 9	
	3	1, 4, 3,	8, 10, 7	
	4	1, 3, 2,	7, 6, 5	
WEDGE	1	1, 2, 5, 4,	7, 11, 13, 10	
	2	2, 3, 6, 5,	8, 12, 14, 11	
	3	1, 4, 6, 3,	10, 15, 12, 9	
	4	1, 3, 2,	9, 8, 7	
	5	4, 5, 6,	13, 14, 15	
HEX	1	1, 2, 6, 5,	9, 14, 17, 13,	26
	2	2, 3, 7, 6,	10, 15, 18, 14,	25
	3	3, 4, 8, 7,	11, 16, 19, 15,	27
	4	1, 5, 8, 4,	13, 20, 16, 12,	24
	5	1, 4, 3, 2,	12, 11, 10, 9,	22
	6	5, 6, 7, 8,	17, 18, 19, 20,	23
PYRAMID	1	1, 2, 5,	6, 11, 10	
	2	2, 3, 5,	7, 12, 11	
	3	3, 4, 5,	8, 13, 12	
	4	4, 1, 5,	9, 10, 13	
	5	1, 4, 3, 2,	9, 8, 7, 6	

Table 4.2: Sideset Node Ordering

4.12 Concatenated Side Sets

API Functions: ex_put_concat_side_sets, ex_get_concat_side_sets

Concatenated side sets provide a means of writing / reading all side sets with one function call. This is more efficient because it avoids some I/O overhead, particularly when considering the intricacies of the `NetCDF` library. This is accomplished with the following lists:

- Side sets IDs – list (of length number of side sets) of unique positive integer side set ID's. The ith entry in this list specifies the ID of the ith side set.
- Side sets side counts – list (of length number of side sets) of counts of sides for each side set. Thus, the ith entry in this list specifies the number of sides in the ith node set. This also defines the number of elements in each side set.
- Side sets distribution factors counts – list (of length number of side sets) of counts of distribution factors for each side set. The ith entry in this list specifies the number of distribution factors in the ith side set.
- Side sets side pointers – list (of length number of side sets) of indices which are pointers into the side sets element list (and side list) locating the first element (or side) of each side set. The ith entry in this list is an index in the side sets element list (and side list) where the first element (or side) of the ith side set can be located.
- Side sets distribution factors pointers – list (of length number of side sets) of indices which are pointers into the side sets distribution factors list locating the first factor of each side set. The ith entry in this list is an index in the side sets distribution factors list where the first factor of the ith side set can be located.
- Side sets element list – concatenated integer list of the elements in all the side sets. Internal element IDs (see Section 4.6) must be used in this list. The side sets side pointers and side sets side counts are used to find the first element and the number of elements in a particular side set.
- Side sets side list – concatenated integer list of the sides in all the side sets. The side sets side pointers and side sets side counts are used to find the first side and the number of sides in a particular side set.
- Side sets distribution factors list – concatenated list of the (floating point) distribution factors in all the side sets. The side sets distribution factors pointers and side sets distribution factors counts are used to find the first factor and the number of factors in a particular side set.

4.12.1 Object Properties

Certain EXODUS objects (currently element blocks, node sets, and side sets) can be given integer properties, providing the following capabilities:

1. assign a specific integer value to a named property of an object.
2. tag objects as members of a group. For example element blocks 1 and 3 and side sets 1 and 2 could be put in a group named "TOP."

Name	EB 1	EB 2	EB 3	NS 1	SS 1	SS 2
ID	1	0	1	0	1	1
TOP	1	1	0	1	1	0
LEFT	0	0	1	NULL	NULL	NULL
STEEL	0	1	1	NULL	NULL	NULL
COPPER	1	1	0	NULL	NULL	NULL

Table 4.3: Example Property Table.

This functionality is illustrated in Table 4.3 which contains the property values of a sample EXODUS file with three element blocks, one node set, and two side sets. Note that an application code can define properties to be valid for only specified object types. In this example, "STEEL" and "COPPER" are valid for all element blocks but are not defined for node sets and side sets.

Interpretation of the integer values of the properties is left to the application codes, but in general, a nonzero positive value means the object has the named property (or is in the named group); a zero means the object does not have the named property (or is not in the named group). Thus, element block 1 has an ID of 10 (1 is a counter internal to the data base; an application code accesses the element block using the ID), node set 1 has an ID of 100, etc. The group "TOP" includes element block 1, element block 3, and side sets 1 and 2.

4.12.2 Property Values

API Functions: ex_put_prop, ex_get_prop, ex_put_prop_array, ex_get_prop_array

Valid values for the properties are positive integers and zero. Property values are stored in arrays in the data file but can be written / read individually given an object type (i.e., element block, node set, or side set), object ID, and property name or as an array given an object type and property name. If accessed as an array, the order of the values in the array must correspond to the order in which the element blocks, node sets, or side sets were introduced into the file. For instance, if the parameters for element block with ID 20 were written to a file, and then parameters for element block with ID 10, followed by the parameters for element block with ID 30, the first, second, and third elements in the property array would correspond to element block 20, element block 10, and element block 30, respectively. This order can be determined with a call to ex_get_elem_blk_ids which returns an array of element block IDs in the order that the corresponding element blocks were introduced to the data file.

4.13 Results Parameters

API Functions: ex_put_variable_param, ex_get_variable_param

The number of each type of results variables (element, nodal, and global) is specified only once, and cannot change through time.

4.13.1 Results Names

API Functions: ex_put_variable_names, ex_get_variable_names

Associated with each results variable is a unique name of length `MAX_STR_LENGTH`.

4.14 Results Data

An integer output time step number (beginning with 1) is used as an index into the results variables written to or read from an EXODUS file. It is a counter of the number of "data planes" that have been written to the file. The maximum time step number (i.e., the number of time steps that have been written) is available via a call to the database inquire function (See Section 5.1.10). For each output time step, the following information is stored.

4.14.1 Time Values

API Functions: ex_put_time, ex_get_time, ex_get_all_times

A floating point value must be stored for each time step to identify the "data plane." Typically, this is the analysis time but can be any floating point variable that distinguishes the time steps. For instance, for a modal analysis, the natural frequency for each mode may be stored as a "time value" to discriminate the different sets of eigen vectors. The only restriction on the time values is that they must monotonically increase.

4.14.2 Global Results

API Functions: ex_put_glob_vars, ex_get_glob_vars, ex_get_glob_var_time

This object contains the floating point global data for the time step. The length of the array is the number of global variables, as specified in the results parameters.

4.14.3 Nodal Results

API Functions: ex_put_nodal_var, ex_get_nodal_var, ex_get_nodal_var_time

This object contains the floating point nodal data for the time step. The size of the array is the number of nodes, as specified in the global parameters, times the number of nodal variables.

4.14.4 Element Results

API Functions: ex_put_elem_var, ex_get_elem_var, ex_get_elem_var_time

Element variables are output for a given element block and a given element variable. Thus, at each time step, up to m element variable objects (where m is the product of the number of element blocks and the number of element variables) may be stored. However, since not all element variables must be output for all element blocks (see the next section), m is the *maximum* number of element variable objects. The actual number of objects stored is the number of unique combinations of element variable index and element block ID passed to ex_put_elem_var or the number of non-zero

	Elem Block 1	Elem Block 2	Elem Block 3	Elem Block 4
Elem Var 1	1	1	1	1
Elem Var 2	1	0	0	1

Table 4.4: Element Variable Truth Table

entries in the element variable truth table (if it is used). The length of each object is the number of elements in the given element block.

4.15 Element Variable Truth Table

API Functions: ex_put_elem_var_tab, ex_get_elem_var_tab

Because some element variables are not applicable (and thus not computed by a simulation code) for all element types, the element variable truth table is an optional mechanism for specifying whether a particular element result is output for the elements in a particular element block. For example, hydrostatic stress may be an output result for the elements in element block 3, but not those in element block 6.

It is helpful to describe the element variable truth table as a two-dimensional array, as shown in Table 4.4, each row of the array is associated with an element variable; each column of the array is associated with an element block. If a datum in the truth table is zero (table$(i, j) = 0$), then no results are output for the i$^{\text{th}}$ element variable for the j$^{\text{th}}$ element block. A nonzero entry indicates that the appropriate result will be output. In this example, element variable 1 will be stored for all element blocks; element variable 2 will be stored for element blocks 1 and 4; and element variable 3 will be stored for element blocks 3 and 4. The table is stored such that the variable index cycles faster than the block index.

Chapter 5

Application Programming Interface (API)

EXODUS files can be written and read by application codes written in C, C++, or Fortran via calls to functions in the application programming interface (API). Functions within the API are categorized as data file utilities, model description functions, or results data functions.

In general, the following pattern is followed for writing data objects to a file:

1. create the file with ex_create;
2. write out global parameters to the file using ex_put_init ;
3. write out specific data object parameters; for example, put out element block parameters with ex_put_elem_block;
4. write out the data object; for example, put out the connectivity for an element block with ex_put_elem_conn;
5. close the file with ex_close .

Steps 3 and 4 are repeated within this pattern for each data object (i.e., nodal coordinates, element blocks, node sets, side sets, results variables, etc.). For some data object types, steps 3 and 4 are combined in a single call. For instance, ex_put_qa writes out the parameters (number of QA records) as well as the data object itself (the QA records). During the database writing process, there are a few order dependencies (e.g., an element block must be written before element variables for that element block are written) which are documented in the description of each library function.

The invocation of the EXODUS API functions for reading data is order independent, providing random read access. The following steps are typically used for reading data:

1. open the file with ex_open;
2. read the global parameters for dimensioning purposes with ex_get_init ;
3. read specific data object parameters; for example, read node set parameters with ex_get_node_set_param;
4. read the data object; for example, read the node set node list with ex_get_node_set;

5. close the file with ex_close.

Again, steps 3 and 4 are repeated for each object. For some object parameters, step 3 may be accomplished with a call to ex_inquire to inquire the size of certain objects.

In developing applications using the EXODUS API, the following points may prove beneficial:

- All functions that write objects to the database begin with ex_put_; functions that read objects from the database begin with ex_get_.
- Function arguments are classified as readable [in], writable [out], or both [inout]. Readable arguments are not modified by the API routines; writable arguments are modified; read-write arguments may be either depending on the value of the argument.
- All application codes which use the EXODUS API must include the file 'exodusII.h' for C. This file defines constants that are used (1) as arguments to the API routines, (2) to set global parameters such as maximum string length and database version, and (3) as error condition or function return values.
- Throughout this section, sample code segments have been included to aid the application developer in using the API routines. These segments are not complete and there has been no attempt to include all calling sequence dependencies within them.
- Because 2-dimensional arrays cannot be statically dimensioned, either dynamic dimensioning or user indexing is required. Most of the sample code segments utilize user indexing within 1-dimensional arrays even though the variables are logically 2-dimensional.
- There are many `NetCDF` utilities that prove useful. ncdump, which converts a binary `NetCDF` file to a readable ASCII version of the file, is the most notable.
- Because `NetCDF` buffers I/O, it is important to flush all buffers with ex_update when debugging an application that produces an EXODUS file.

5.1 Data File Utilities

This section describes data file utility functions for creating / opening a file, initializing a file with global parameters, reading / writing information text, inquiring on parameters stored in the data file, and error reporting.

5.1.1 Create EXODUS File

The function ex_create creates a new EXODUS file and returns an ID that can subsequently be used to refer to the file.

All floating point values in an EXODUS file are stored as either 4-byte ("float") or 8-byte ("double") numbers; no mixing of 4- and 8-byte numbers in a single file is allowed. An application code can compute either 4- or 8-byte values and can designate that the values be stored in the EXODUS file as either 4- or 8-byte numbers; conversion between the 4- and 8-byte values is performed automatically by the API routines. Thus, there are four possible combinations of compute word size and storage (or I/O) word size.

In case of an error, ex_create returns a negative number. Possible causes of errors include:

- Passing a file name that includes a directory that does not exist.
- Specifying a file name of a file that exists and also specifying a no clobber option.
- Attempting to create a file in a directory without permission to create files there.
- Passing an invalid file clobber mode.

```
int ex_create (char *path,
               int mode,
               int *comp_ws,
               int *io_ws)
```

`char* path` [in]

The file name of the new EXODUS file. This can be given as either an absolute path name (from the root of the file system) or a relative path name (from the current directory).

`int mode` [in]

Mode. Use one of the following predefined constants:

`EX_NOCLOBBER` To create the new file only if the given file name does not refer to a file that already exists.

`EX_CLOBBER` To create the new file, regardless of whether a file with the same name already exists. If a file with the same name does exist, its contents will be erased.

`EX_LARGE_MODEL` To create a model that can store individual datasets larger than 2 gigabytes. This modifies the internal storage used by exodusII and also puts the underlying `NetCDF` file into the "64-bit offset" mode. See Appendix ?? for more details on this mode.[1]

`EX_NORMAL_MODEL` Create a standard model.

`EX_NETCDF4` To create a model using the `HDF5`-based `NetCDF-4` output. (Future capability)[2]

`EX_NOSHARE` Do not open the underlying `NetCDF` file in "share" mode. See the `NetCDF` documentation for more details.

`EX_SHARE` Do open the underlying `NetCDF` file in "share" mode. See the `NetCDF` documentation for more details.

`int* comp_ws` [inout]

The word size in bytes (0, 4 or 8) of the floating point variables used in the application program. If 0 (zero) is passed, the default sizeof(float) will be used and returned in this variable. WARNING: all EXODUS functions requiring floats must be passed floats declared with this passed in or returned compute word size (4 or 8).

`int* io_ws` [in]

The word size in bytes (4 or 8) of the floating point data as they are to be stored in the EXODUS file.

[1] A "large model" file will also be created if the environment variable `EXODUS_LARGE_MODEL` is defined in the users environment. A message will be printed to standard output if this environment variable is found.

[2] `NetCDF-4` is currently in beta mode; however, it will be used for ExodusII when available, so this mode is being defined here for future completeness. An `HDF5`-based `NetCDF-4` file will also be created if the environment variable `EXODUS_NETCDF4` is defined in the users environment. A message will be printed to standard output if this environment variable is found.

The following code segment creates an EXODUS file called ***test.exo***:

```
#include "exodusII.h"
int CPU_word_size, IO_word_size, exoid;
CPU_word_size = sizeof(float); /* use float or double */
IO_word_size = 8; /* store variables as doubles */

/* create \exo{} file */
exoid = ex_create ("test.exo"      /* filename path */
                   EX_CLOBBER,      /* create mode */
                   &CPU_word_size, /* CPU float word size in bytes */
                   &IO_word_size); /* I/O float word size in bytes */
```

5.1.2 Open EXODUS File

The function ex_open opens an existing EXODUS file and returns an ID that can subsequently be used to refer to the file, the word size of the floating point values stored in the file, and the version of the EXODUS database (returned as a "float", regardless of the compute or I/O word size). Multiple files may be "open" simultaneously.

In case of an error, ex_open returns a negative number. Possible causes of errors include:

- The specified file does not exist.
- The mode specified is something other than the predefined constant `EX_READ` or `EX_WRITE`.
- Database version is earlier than 2.0.

```
int ex_open (char *path,
             int mode,
             int *comp_ws,
             int *io_ws,
             float *version)
```

`char* path` [in]

The file name of the EXODUS file. This can be given as either an absolute path name (from the root of the file system) or a relative path name (from the current directory).

`int mode` [in]

Access mode. Use one of the following predefined constants:
EX˙READ To open the file just for reading.

EX˙WRITE To open the file for writing and reading.

`int* comp_ws` [inout]

The word size in bytes (0, 4 or 8) of the floating point variables used in the application program. If 0 (zero) is passed, the default size of floating point values for the machine will be used and returned in this variable. WARNING: all EXODUS functions requiring reals must be passed reals declared with this passed in or returned compute word size (4 or 8).

`int* io_ws` [inout]

The word size in bytes (0, 4 or 8) of the floating point data as they are stored in the EXODUS file. If the word size does not match the word size of data stored in the file, a fatal error is returned. If this argument is 0, the word size of the floating point data already stored in the file is returned.

`float* version` [out]

Returned EXODUS database version number. The current version is 4.72

The following opens an EXODUS file named ***test.exo*** for read only, using default settings for compute and I/O word sizes:

```
#include "exodusII.h"
int CPU_word_size,IO_word_size, exoid;
float version;

CPU_word_size = sizeof(float);    /* float or double */
IO_word_size = 0;                 /* use what is stored in file */

/* open \exo{} files */
exoid = ex_open ("test.exo",      /* filename path */
                 EX_READ,         /* access mode = READ */
                 &CPU_word_size,  /* CPU word size */
                 &IO_word_size,   /* IO word size */
                 &version);       /* ExodusII library version */
```

5.1.3 Close EXODUS File

The function ex_close updates and then closes an open EXODUS file.

In case of an error, ex_close returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open

`int ex_close (int exoid)`

`int exoid` [in]

EXODUS file ID returned from a previous call to ex_create or ex_open.

The following code segment closes an open EXODUS file:

```
int error,exoid;
error = ex_close (exoid);
```

5.1.4 Write Initialization Parameters

The function ex_put_init writes the initialization parameters to the EXODUS file. This function must be called once (and only once) before writing any data to the file.

In case of an error, ex_put_init returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.
- this routine has been called previously.

```
int ex_put_init (int exoid,
                 char *title,
                 int num_dim,
                 int num_nodes,
                 int num_elem,
                 int num_elem_blk,
                 int num_node_sets,
                 int num_side_sets)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`char* titletitle` [in]
: Database title. Maximum length is `MAX_LINE_LENGTH`.

`int num_dim` [in]
: The dimensionality of the database. This is the number of coordinates per node.

`int num_nodes` [in]
: The number of nodal points.

`int num_elem` [in]
: The number of elements.

`int num_elem_blk` [in]
: The number of element blocks.

`int num_node_sets` [in]
: The number of node sets.

`int num_side_sets` [in]
: The number of side sets.

The following code segment will initialize an open EXODUS file with the specified parameters:

```
int num_dim, num_nods, num_el, num_el_blk, num_ns, num_ss, error, exoid;

/* initialize file with parameters */
num_dim = 3; num_nods = 46; num_el = 5; num_el_blk = 5;
num_ns = 2; num_ss = 5;

error = ex_put_init (exoid, "This is the title", num_dim,
                     num_nods, num_el,num_el_blk, num_ns, num_ss);
```

5.1.5 Read Initialization Parameters

The function ex_get_init reads the initialization parameters from an opened EXODUS file.

In case of an error, ex_get_init returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open.

```
int ex_get_init (int exoid,
                 char *title,
                 int num_dim,
                 int num_nodes,
                 int num_elem,
                 int num_elem_blk,
                 int num_node_sets,
                 int num_side_sets)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`char* titletitle` [out]
: Returned database title. String length may be up to `MAX_LINE_LENGTH` bytes.

`int* num_dim` [out]
: Returned dimensionality of the database. This is the number of coordinates per node.

`int* num_nodes` [out]
: Returned number of nodal points.

`int* num_elem` [out]
: Returned number of elements.

`int* num_elem_blk` [out]
: Returned number of element blocks.

`int* num_node_sets` [out]
: Returned number of node sets.

`int* num_side_sets` [out]
: Returned number of side sets.

The following code segment will read the initialization parameters from the open EXODUS file:

```
#include "exodusII.h"
int num_dim, num_nodes, num_elem, num_elem_blk,
    num_node_sets, num_side_sets, error, exoid;

char title[MAX_LINE_LENGTH+1];
```

```

/* read database parameters */
error = ex_get_init (exoid, title, &num_dim, &num_nodes,
                     &num_elem, &num_elem_blk, &num_node_sets, &num_side_sets);
```

5.1.6 Write Quality Assurance (QA) Records

The function ex_put_qa writes the QA records to the database. Each QA record contains four MAX_STR_LENGTH-byte character strings. The character strings are:

- the analysis code name
- the analysis code QA descriptor
- the analysis date
- the analysis time

In case of an error, ex_put_qa returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.
- QA records already exist in file.

```
int ex_put_qa (int exoid,
               int num_qa_records,
               char *qa_record[][4])
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int num_qa_records` [in]
: The number of QA records.

`char* qa_record` [in]
: Array containing the QA records.

The following code segment will write out two QA records:

```
#include "exodusII.h"
int num_qa_rec, error, exoid;
char *qa_record[2][4];

/* write QA records */
num_qa_rec = 2;

qa_record[0][0] = "TESTWT1";
```

```
qa_record[0][1] = "testwt1";
qa_record[0][2] = "07/07/93";
qa_record[0][3] = "15:41:33";
qa_record[1][0] = "FASTQ";
qa_record[1][1] = "fastq";
qa_record[1][2] = "07/07/93";
qa_record[1][3] = "16:41:33";

error = ex_put_qa (exoid, num_qa_rec, qa_record);
```

5.1.7 Read Quality Assurance (QA) Records

The function ex_get_qa reads the QA records from the database. Each QA record contains four MAX_STR_LENGTH-byte character strings. The character strings are:

- the analysis code name
- the analysis code QA descriptor
- the analysis date
- the analysis time

Memory must be allocated for the QA records before this call is made. The number of QA records can be determined by invoking ex_inquire.

In case of an error, ex_get_qa returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- a warning value is returned if no QA records were stored.

```
int ex_get_qa (int exoid,
               char *qa_record[][4])
```

int exoid [in]
EXODUS file ID returned from a previous call to ex_create or ex_open.

char* qa_record [out]
Returned array containing the QA records.

The following will determine the number of QA records and read them from the open EXODUS file:

```
#include "exodusII.h"
int num_qa_rec, error, exoid
char *qa_record[MAX_QA_REC][4];

/* read QA records */
num_qa_rec = ex_inquire_int(exoid, EX_INQ_QA);

```

```
for (i=0; i\texttt{<}num_qa_rec; i++) {
    for (j=0; j\texttt{<}4; j++)
    qa_record[i][j] = (char *) calloc ((MAX_STR_LENGTH+1), sizeof(char));
}
error = ex_get_qa (exoid, qa_record);
```

5.1.8 Write Information Records

The function ex_put_info writes information records to the database. The records are MAX˙LINE˙LENGTH-character strings.

In case of an error, ex_put_info returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.
- information records already exist in file.

```
int ex_put_info (int exoid,
                 int num_info,
                 char **info)
```

`int exoid` [in]
EXODUS file ID returned from a previous call to ex_create or ex_open.

`int num_info` [in]
The number of information records.

`char** info` [in]
Array containing the information records.

The following code will write out three information records to an open EXODUS file:

```
#include "exodusII.h"
int error, exoid, num_info;
char *info[3];

/* write information records */
num_info = 3;

info[0] = "This is the first information record.";
info[1] = "This is the second information record.";
info[2] = "This is the third information record.";

error = ex_put_info(exoid, num_info, info);
```

5.1.9 Read Information Records

The function ex_get_info reads information records from the database. The records are `MAX_LINE_LENGTH`-character strings. Memory must be allocated for the information records before this call is made. The number of records can be determined by invoking ex_inquire or ex_inquire_int .

In case of an error, ex_get_info returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- a warning value is returned if no information records were stored.

```
int ex_get_info (int exoid,
                 char‘**info)
```

`int exoid` [in]
  EXODUS file ID returned from a previous call to ex_create or ex_open.

`char** info` [out]
  Returned array containing the information records.

The following code segment will determine the number of information records and read them from an open EXODUS file:

```
#include "exodusII.h"
int error, exoid, num_info;
char *info[MAXINFO];

/* read information records */
num_info = ex_inquire_int (exoid,EX_INQ_INFO);
for (i=0; i < num_info; i++) {
   info[i] = (char *) calloc ((MAX_LINE_LENGTH+1), sizeof(char));
}
error = ex_get_info (exoid, info);
```

5.1.10 Inquire EXODUS Parameters

The function ex_inquire is used to inquire values of certain data entities in an EXODUS file. Memory must be allocated for the returned values before this function is invoked.query database

In case of an error, ex_inquire returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open.
- requested information not stored in the file.
- invalid request flag.

```
int ex_inquire (int exoid,
                ex_inquiry req_info,
                int *ret_int,
                float *ret_float,
                char *ret_char)
```

`int exoid` [in]

EXODUS file ID returned from a previous call to ex_create or ex_open.

`ex_inquiry req_info` [in]

A flag which designates what information is requested. It must be one of the following constants (predefined in the file ***exodusII.h***):

`EX_INQ_API_VERS`	The EXODUS API version number is returned in `ret_float` and an "undotted" version number is returned in `ret_int`. The API version number reflects the release of the function library (i.e., function names, argument list, etc.). The current API version is 4.72 or 472[3].
`EX_INQ_DB_VERS`	The EXODUS database version number is returned in `ret_float` and an "undotted" version number is returned in `ret_int`. The database version number reflects the version of the library that was used to write the file pointed to by `exoid`. The current database version is 4.72 or 472.
`EX_INQ_LIB_VERS`	The EXODUS library version number is returned in `ret_float` and an "undotted" version number is returned in `ret_int`. The API library version number reflects the version number of the EXODUS library linked with this application. The current library version is 4.72 or 472
`EX_INQ_TITLE`	The title stored in the database is returned in `ret_char`.
`EX_INQ_DIM`	The dimensionality, or number of coordinates per node (1, 2 or 3), of the database is returned in `ret_int`.
`EX_INQ_NODES`	The number of nodes is returned in `ret_int`.
`EX_INQ_ELEM`	The number of elements is returned in `ret_int`.
`EX_INQ_ELEM_BLK`	The number of element blocks is returned in `ret_int`.
`EX_INQ_NODE_SETS`	The number of node sets is returned in `ret_int`.
`EX_INQ_NS_NODE_LEN`	The length of the concatenated node sets node list is returned in `ret_int`.
`EX_INQ_NS_DF_LEN`	The length of the concatenated node sets distribution list is returned in `ret_int`.
`EX_INQ_SIDE_SETS`	The number of side sets is returned in `ret_int`.
`EX_INQ_SS_ELEM_LEN`	The length of the concatenated side sets element list is returned in `ret_int`.
`EX_INQ_SS_DF_LEN`	The length of the concatenated side sets distribution factor list is returned in `ret_int`.
`EX_INQ_SS_NODE_LEN`	The aggregate length of all of the side sets node lists is returned in `ret_int`.
`EX_INQ_EB_PROP`	The number of integer properties stored for each element block is returned in `ret_int`; this number includes the property named "ID".
`EX_INQ_NS_PROP`	The number of integer properties stored for each node set is returned in `ret_int`; this number includes the property named "ID".

[3] The API and DB version numbers are synchronized and will always match. Initially, it was thought that maintaining the two versions separately would be a benefit, but that was more confusing than helpful, so the numbers were made the same awhile ago

`EX_INQ_SS_PROP`	The number of integer properties stored for each side set is returned in `ret_int`; this number includes the property named "ID".
`EX_INQ_QA`	The number of QA records is returned in `ret_int`.
`EX_INQ_INFO`	The number of information records is returned in `ret_int`.
`EX_INQ_TIME`	The number of time steps stored in the database is returned in `ret_int`.
`EX_INQ_EDGE_BLK`	The number of edge blocks is returned in `ret_int`.
`EX_INQ_EDGE_MAP`	The number of edge maps is returned in `ret_int`.
`EX_INQ_EDGE_PROP`	The number of properties stored per edge blockis returned in `ret_int`.
`EX_INQ_EDGE_SETS`	The number of edge sets is returned in `ret_int`.
`EX_INQ_EDGE`	The number of edges is returned in `ret_int`.
`EX_INQ_FACE`	The number of faces is returned in `ret_int`.
`EX_INQ_EB_PROP`	The number of element block properties is returned in `ret_int`.
`EX_INQ_ELEM_MAP`	The number of element maps is returned in `ret_int`.
`EX_INQ_ELEM_SETS`	The number of element sets is returned in `ret_int`.
`EX_INQ_ELS_DF_LEN`	The length of the concatenated element set distribution factor list is returned in `ret_int`.
`EX_INQ_ELS_LEN`	The length of the concatenated element set element list is returned in `ret_int`.
`EX_INQ_ELS_PROP`	The number of properties stored per elem set is returned in `ret_int`.
`EX_INQ_EM_PROP`	The number of element map properties is returned in `ret_int`.
`EX_INQ_ES_DF_LEN`	The length of the concatenated edge set distribution factor list is returned in `ret_int`.
`EX_INQ_ES_LEN`	The length of the concatenated edge set edge list is returned in `ret_int`.
`EX_INQ_ES_PROP`	The number of properties stored per edge set is returned in `ret_int`.
`EX_INQ_FACE_BLK`	The number of face blocks is returned in `ret_int`.
`EX_INQ_FACE_MAP`	The number of face maps is returned in `ret_int`.
`EX_INQ_FACE_PROP`	The number of properties stored per face block is returned in `ret_int`.
`EX_INQ_FACE_SETS`	The number of face sets is returned in `ret_int`.
`EX_INQ_FS_DF_LEN`	The length of the concatenated face set distribution factor list is returned in `ret_int`.
`EX_INQ_FS_LEN`	The length of the concatenated face set face list is returned in `ret_int`.
`EX_INQ_FS_PROP`	The number of properties stored per face set is returned in `ret_int`.
`EX_INQ_NM_PROP`	The number of node map properties is returned in `ret_int`.
`EX_INQ_NODE_MAP`	The number of node maps is returned in `ret_int`.

`int* ret_int` [out]

Returned integer, if an integer value is requested according to `req_info`); otherwise, supply a dummy argument.

`float* ret_float` [out]

Returned float, if a float value is requested (according to `req_info`); otherwise, supply a dummy argument[4].

`char* ret_char` [out]

Returned character string, if a character value is requested according to `req_info`); otherwise, supply a dummy argument.

As an example, the following will return the number of element block properties stored in the EXODUS file:

[4] NOTE: This argument is always a float even if the database IO and/or CPU word size is a double.

```
#include "exodusII.h"
int error, exoid, num_props;
float fdum;
char *cdum;

/* determine the number of element block properties */
error = ex_inquire (exoid, EX_INQ_EB_PROP, &num_props,
                    &fdum, cdum);
```

5.1.11 Inquire EXODUS Integer Parameters

The function ex_inquire_int is used to query or inquire values of certain integer data entities in an EXODUS file. It is a short-cut to the ex_inquire function defined in the previous section. If there is no error, the queried value will be returned as a positive number. In case of an error, ex_inquire returns a negative number.

- data file not properly opened with call to ex_create or ex_open.
- requested information not stored in the file.
- invalid request flag.

```
int ex_inquire_int (int exoid,
                    ex_inquiry req_info)
```

`int exoid` [in]
EXODUS file ID returned from a previous call to ex_create or ex_open.

`ex_inquiry req_info` [in]
A flag which designates what information is requested. It must be one of the following constants (predefined in the file ***exodusII.h***):

`EX_INQ_API_VERS`	The "undotted" EXODUS API version number is returned. The API version number reflects the release of the function library (i.e., function names, argument list, etc.). The current "undotted" API version is 472.
`EX_INQ_LIB_VERS`	The "undotted" EXODUS API library version number is returned. The API library version number reflects the format of the data as it is stored in the `NetCDF` database. The current API version is 472
`EX_INQ_DB_VERS`	The "undotted" EXODUS database version number is returned. The database version number reflects the version of the library that was used to write the file pointed to by `exoid`. The current database version is 472.
`EX_INQ_DIM`	The dimensionality, or number of coordinates per node (1, 2 or 3), of the database is returned.
`EX_INQ_NODES`	The number of nodes is returned.
`EX_INQ_ELEM`	The number of elements is returned.
`EX_INQ_ELEM_BLK`	The number of element blocks is returned.
`EX_INQ_NODE_SETS`	The number of node sets is returned.
`EX_INQ_NS_NODE_LEN`	The length of the concatenated node sets node list is returned.
`EX_INQ_NS_DF_LEN`	The length of the concatenated node sets distribution list is returned.

`EX_INQ_SIDE_SETS`	The number of side sets is returned.
`EX_INQ_SS_ELEM_LEN`	The length of the concatenated side sets element list is returned.
`EX_INQ_SS_DF_LEN`	The length of the concatenated side sets distribution factor list is returned.
`EX_INQ_SS_NODE_LEN`	The aggregate length of all of the side sets node lists is returned.
`EX_INQ_EB_PROP`	The number of integer properties stored for each element block is returned; this number includes the property named "ID".
`EX_INQ_NS_PROP`	The number of integer properties stored for each node set is returned; this number includes the property named "ID".
`EX_INQ_SS_PROP`	The number of integer properties stored for each side set is returned; this number includes the property named "ID".
`EX_INQ_QA`	The number of QA records is returned.
`EX_INQ_INFO`	The number of information records is returned.
`EX_INQ_TIME`	The number of time steps stored in the database is returned.
`EX_INQ_EDGE_BLK`	The number of edge blocks is returned.
`EX_INQ_EDGE_MAP`	The number of edge maps is returned.
`EX_INQ_EDGE_PROP`	The number of properties stored per edge block is returned.
`EX_INQ_EDGE_SETS`	The number of edge sets is returned.
`EX_INQ_EDGE`	The number of edges is returned.
`EX_INQ_FACE`	The number of faces is returned.
`EX_INQ_EB_PROP`	The number of element block properties is returned.
`EX_INQ_ELEM_MAP`	The number of element maps is returned.
`EX_INQ_ELEM_SETS`	The number of element sets is returned.
`EX_INQ_ELS_DF_LEN`	The length of the concatenated element set distribution factor list is returned.
`EX_INQ_ELS_LEN`	The length of the concatenated element set element list is returned.
`EX_INQ_ELS_PROP`	The number of properties stored per elem set is returned.
`EX_INQ_EM_PROP`	The number of element map properties is returned.
`EX_INQ_ES_DF_LEN`	The length of the concatenated edge set distribution factor list is returned.
`EX_INQ_ES_LEN`	The length of the concatenated edge set edge list is returned.
`EX_INQ_ES_PROP`	The number of properties stored per edge set is returned.
`EX_INQ_FACE_BLK`	The number of face blocks is returned.
`EX_INQ_FACE_MAP`	The number of face maps is returned.
`EX_INQ_FACE_PROP`	The number of properties stored per face block is returned.
`EX_INQ_FACE_SETS`	The number of face sets is returned.
`EX_INQ_FS_DF_LEN`	The length of the concatenated face set distribution factor list is returned.
`EX_INQ_FS_LEN`	The length of the concatenated face set face list is returned.
`EX_INQ_FS_PROP`	The number of properties stored per face set is returned.
`EX_INQ_NM_PROP`	The number of node map properties is returned.
`EX_INQ_NODE_MAP`	The number of node maps is returned.

As an example, the following will return the number of nodes, elements, and element blocks stored in the EXODUS file:

```c
#include "exodusII.h"
int exoid;
int num_nodes = ex_inquire_int(exoid, EX_INQ_NODES);
int num_elems = ex_inquire_int(exoid, EX_INQ_ELEM);
int num_block = ex_inquire_int(exoid, EX_INQ_ELEM_BLK);
```

5.1.12 Error Reporting

The function ex_err logs an error to `stderr`. It is intended to provide explanatory messages for error codes returned from other EXODUS routines.This function

The passed in error codes and corresponding messages are listed in Appendix C. The programmer may supplement the error message printed for standard errors by providing an error message. If the error code is provided with no error message, the predefined message will be used. The error code `EX_MSG` is available to log application specific messages.

```
void ex_err (char *module_name,
             char *message,
             int err_num)
```

`char* module_name` [in]
: This is a string containing the name of the calling function.

`char* message` [in]
: This is a string containing a message explaining the error or problem. If `EX_VERBOSE` (see ex_opts) is true, this message will be printed to `stderr`. Otherwise, nothing will be printed.

`int err_num` [in]
: This is an integer code identifying the error. EXODUS C functions place an error code value in `exerrval`, an external int. Negative values are considered fatal errors while positive values are warnings. There is a set of predefined values defined in ***exodusII.h***. The predefined constant `EX_PRTLASTMSG` will cause the last error message to be output, regardless of the setting of the error reporting level (see ex_opts).

The following is an example of the use of this function:

```
#include "exodusII.h"
int exoid, CPU_word_size, IO_word_size, errval;
float version;
char errmsg[MAX_ERR_LENGTH];

CPU_word_size = sizeof(float);
IO_word_size = 0;

/* open \exo{} file */
if (exoid = ex_open ("test.exo", EX_READ, &CPU_word_size,
                     &IO_word_size, &version)) {
   errval = 999;
   sprintf(errmsg,"Error: cannot open file test.exo");
   ex_err("prog_name", errmsg, errval);
}
```

5.1.13 Set Error Reporting Level

The function ex_opts is used to set message reporting options.

In case of an error, ex_opts returns a negative number; a warning will return a positive number.

`int ex_opts (ex_options option_val)`

`int option_val` [in]
Integer option value. Current options are:

- `EX_ABORT` Causes fatal errors to force program exit. (Default is false.)
- `EX_DEBUG` Causes certain messages to print for debug use. (Default is false.)
- `EX_VERBOSE` Causes all error messages to print when true, otherwise no error messages will print. (Default is false.)

NOTE: Values may be OR'ed together to provide any combination of these capabilities.

For example, the following will cause all messages to print and will cause the program to exit upon receipt of fatal error:

```
#include "exodusII.h"
ex_opts(EX_ABORT|EX_VERBOSE);
```

5.2 Model Description

The routines in this section read and write information which describe an EXODUS finite element model. This includes nodal coordinates, element order map, element connectivity arrays, element attributes, node sets, side sets, and object properties.

5.2.1 Write Nodal Coordinates

The function ex_put_coord writes the nodal coordinates of the nodes in the model. The function ex_put_init must be invoked before this call is made.

Because the coordinates are floating point values, the application code must declare the arrays passed to be the appropriate type ("float" or "double") to match the compute word size passed in ex_create or ex_open.

In case of an error, ex_put_coord returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.
- data file not initialized properly with call to ex_put_init .

```
int ex_put_coord (int exoid,
                  void *x_coor,
                  void *y_coor,
                  void *z_coor)
```

`int exoid` [in]
EXODUS file ID returned from a previous call to ex_create or ex_open.

`void* x_coor` [in]
: The X-coordinates of the nodes. If this is `NULL`, the X-coordinates will not be written.

`void* y_coor` [in]
: The Y-coordinates of the nodes. These are stored only if `num_dim` > 1; otherwise, pass in dummy address. If this is `NULL`, the Y-coordinates will not be written.

`void* z_coor` [in]
: The Z-coordinates of the nodes. These are stored only if `num_dim` > 2; otherwise, pass in dummy address. If this is `NULL`, the Z-coordinates will not be written.

The following will write the nodal coordinates to an open EXODUS file:

```c
int error, exoid;

/* if file opened with compute word size of sizeof(float) */
float x[8], y[8], z[8];

/* write nodal coordinates values to database */
x[0] = 0.0; y[0] = 0.0; z[0] = 0.0;
x[1] = 0.0; y[1] = 0.0; z[1] = 1.0;
x[2] = 1.0; y[2] = 0.0; z[2] = 1.0;
x[3] = 1.0; y[3] = 0.0; z[3] = 0.0;
x[4] = 0.0; y[4] = 1.0; z[4] = 0.0;
x[5] = 0.0; y[5] = 1.0; z[5] = 1.0;
x[6] = 1.0; y[6] = 1.0; z[6] = 1.0;
x[7] = 1.0; y[7] = 1.0; z[7] = 0.0;

error = ex_put_coord(exoid, x, y, z);

/* Do the same as the previous call in three separate calls */
error = ex_put_coord(exoid, x,    NULL, NULL);
error = ex_put_coord(exoid, NULL, y,    NULL);
error = ex_put_coord(exoid, NULL, NULL, z);
```

5.2.2 Read Nodal Coordinates

The function ex_get_coord reads the nodal coordinates of the nodes. Memory must be allocated for the coordinate arrays (`x_coor`, `y_coor`, and `z_coor`) before this call is made. The length of each of these arrays is the number of nodes in the mesh.

Because the coordinates are floating point values, the application code must declare the arrays passed to be the appropriate type ("float" or "double") to match the compute word size passed in ex_create or ex_open.

In case of an error, ex_get_coord returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- a warning value is returned if nodal coordinates were not stored.

```
int ex_get_coord (int exoid,
                  void *x_coor,
                  void *y_coor,
                  void *z_coor)
```

`int exoid` [in]

EXODUS file ID returned from a previous call to ex_create or ex_open.

`void* x_coor` [out]

Returned X coordinates of the nodes. If this is `NULL`, the X-coordinates will not be read.

`void* y_coor` [out]

Returned Y coordinates of the nodes. These are returned only if num_dim > 1; otherwise, pass in a dummy address. If this is `NULL`, the Y-coordinates will not be read.

`void* z_coor` [out]

Returned Z coordinates of the nodes. These are returned only if num_dim > 2; otherwise, pass in a dummy address. If this is `NULL`, the Z-coordinates will not be read.

The following code segment will read the nodal coordinates from an open EXODUS file:

```
int error, exoid;

float *x, *y, *z;

/* read nodal coordinates values from database */
x = (float *)calloc(num_nodes, sizeof(float));
y = (float *)calloc(num_nodes, sizeof(float));
if (num_dim >= 3)
   z = (float *)calloc(num_nodes, sizeof(float));
else
   z = 0;

error = ex_get_coord(exoid, x, y, z);

/* Do the same as the previous call in three separate calls */
error = ex_get_coord(exoid, x,    NULL, NULL);
error = ex_get_coord(exoid, NULL, y,    NULL);
if (num_dim >= 3)
   error = ex_get_coord(exoid, NULL, NULL, z);
```

5.2.3 Write Coordinate Names

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.
- data file not initialized properly with call to ex_put_init.

```
int ex_put_coord_names (int exoid,
                        char **coord_names)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`char** coord_names` [in]
: Array containing `num_dim` names of length `MAX_STR_LENGTH` of the nodal coordinate arrays.

The following coding will write the coordinate names to an open EXODUS file:

```
int error, exoid;

char *coord_names[3];
coord_names[0] = "xcoor";
coord_names[1] = "ycoor";
coord_names[2] = "zcoor";

error = ex_put_coord_names (exoid, coord_names);
```

5.2.4 Read Coordinate Names

The function ex_get_coord_names reads the names (`MAX_STR_LENGTH`-characters in length) of the coordinate arrays from the database. Memory must be allocated for the character strings before this function is invoked.

In case of an error, ex_get_coord_names returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- a warning value is returned if coordinate names were not stored.

```
int ex_get_coord_names (int exoid,
                        char **coord_names)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`char** coord_names` [out]
: Returned pointer to a vector containing `num_dim` names of the nodal coordinate arrays.

The following code segment will read the coordinate names from an open EXODUS file:

```
int error, exoid;
char *coord_names[3];

for (i=0; i < num_dim; i++) {
   coord_names[i] = (char *)calloc((MAX_STR_LENGTH+1), sizeof(char));
}

error = ex_get_coord_names (exoid, coord_names);
```

5.2.5 Write Node Number Map

The function ex_put_node_num_map writes out the optional node number map to the database. See Section 4.5 for a description of the node number map. The function ex_put_init must be invoked before this call is made.

In case of an error, ex_put_node_num_map returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.
- data file not initialized properly with call to ex_put_init.
- a node number map already exists in the file.

```
int ex_put_node_num_map (int exoid,
                         int *node_map)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int* node_map` [in]
: The node number map.

The following code generates a default node number map and outputs it to an open EXODUS file. This is a trivial case and included just for illustration. Since this map is optional, it should be written out only if it contains something other than the default map.

```
int error, exoid;
int *node_map = (int *)calloc(num_nodes, sizeof(int));

for (i=1; i <= num_nodes; i++)
   node_map[i-1] = i;

error = ex_put_node_num_map(exoid, node_map);
```

5.2.6 Read Node Number Map

The function ex_get_node_num_map reads the optional node number map from the database. See Section 4.5 for a description of the node number map. If a node number map is not stored in the data file, a default array (1,2,3,. .. `num_nodes`) is returned. Memory must be allocated for the node number map array (num˙nodes in length) before this call is made.

In case of an error, ex_get_node_num_map returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- if a node number map is not stored, a default map and a warning value are returned.

```
int ex_get_node_num_map (int exoid,
                         int *node_map)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int* node_map` [out]
: Returned node number map.

The following code will read a node number map from an open EXODUS file:

```
int *node_map, error, exoid;

/* read node number map */
node_map = (int *)calloc(num_nodes, sizeof(int));
error = ex_get_node_num_map(exoid, node_map);
```

5.2.7 Write Element Number Map

The function ex_put_elem_num_map writes out the optional element number map to the database. See Section 4.6 for a description of the element number map. The function ex_put_init must be invoked before this call is made.

In case of an error, ex_put_elem_num_map returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.
- data file not initialized properly with call to ex_put_init.
- an element number map already exists in the file.

```
int ex_put_elem_num_map (int exoid,
                         int *elem_map)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int* elem_map` [in]
: The element number map.

The following code generates a default element number map and outputs it to an open EXODUS file. This is a trivial case and included just for illustration. Since this map is optional, it should be written out only if it contains something other than the default map.

```
int error, exoid;
int *elem_map = (int *)calloc(num_elem, sizeof(int));

```

```
for (i=1; i <= num_elem; i++)
   elem_map[i-1] = i;

error = ex_put_elem_num_map(exoid, elem_map);
```

5.2.8 Read Element Number Map

The function ex_get_elem_num_map reads the optional element number map from the database. See Section 4.6 for a description of the element number map. If an element number map is not stored in the data file, a default array (1,2,3,. .. `num_elem`) is returned. Memory must be allocated for the element number map array (num˙elem in length) before this call is made.

In case of an error, ex_get_elem_num_map returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- if an element number map is not stored, a default map and a warning value are returned.

```
int ex_get_elem_num_map (int exoid,
                         int *elem_map)
```

`int exoid` [in]
EXODUS file ID returned from a previous call to ex_create or ex_open.

`int* elem_map` [out]
Returned element number map.

The following code will read an element number map from an open EXODUS file:

```
int *elem_map, error, exoid;

/* read element number map */
elem_map = (int *) calloc(num_elem, sizeof(int));
error = ex_get_elem_num_map (exoid, elem_map);
```

5.2.9 Write Element Order Map

The function ex_put_map writes out the optional element order map to the database. See Section 4.7 for a description of the element order map. The function ex_put_init must be invoked before this call is made.

In case of an error, ex_put_map returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.
- data file not initialized properly with call to ex_put_init.

- an element map already exists in the file.

```
int ex_put_map (int exoid,
                int *elem_map)
```

`int exoid` [in]
    EXODUS file ID returned from a previous call to ex_create or ex_open.

`int* elem_map` [in]
    The element order map.

The following code generates a default element order map and outputs it to an open EXODUS file. This is a trivial case and included just for illustration. Since this map is optional, it should be written out only if it contains something other than the default map.

```
int error, exoid;
int *elem_map = (int *)calloc(num_elem, sizeof(int));
for (i=0; i < num_elem; i++) {
   elem_map[i] = i+1;
}
error = ex_put_map(exoid, elem_map);
```

5.2.10 Read Element Order Map

The function ex_get_map reads the element order map from the database. See Section 4.7 for a description of the element order map. If an element order map is not stored in the data file, a default array (1,2,3,. .. `num_elem`) is returned. Memory must be allocated for the element map array (num˙elem in length) before this call is made.

In case of an error, ex_get_map returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- if an element order map is not stored, a default map and a warning value are returned.

```
int ex_get_map (int exoid,
                int *elem_map)
```

`int exoid` [in]
    EXODUS file ID returned from a previous call to ex_create or ex_open.

`int* elem_map` [out]
    Returned element order map.

The following code will read an element order map from an open EXODUS file:

```
int *elem_map, error, exoid;

```

```
/* read element order map */
elem_map = (int *)calloc(num_elem , sizeof(int));

error = ex_get_map(exoid , elem_map);
```

5.2.11 Write Element Block Parameters

The function ex_put_elem_block writes the parameters used to describe an element block.

In case of an error, ex_put_elem_block returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.
- data file not initialized properly with call to ex_put_init .
- an element block with the same ID has already been specified.
- the number of element blocks specified in the call to ex_put_init has been exceeded.

```
int ex_put_elem_block (int exoid,
                       int elem_blk_id,
                       char *elem_type,
                       int num_elem_this_blk,
                       int num_nodes_per_elem,
                       int num_attr)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int elem_blk_id` [in]
: The element block ID.

`char* elem_type` [in]
: The type of elements in the element block. The maximum length of this string is `MAX_STR_LENGTH`.

`int num_elem_this_blk` [in]
: The number of elements in the element block.

`int num_nodes_per_elem` [in]
: The number of nodes per element in the element block.

`int num_attr` [in]
: The number of attributes per element in the element block.

For example, the following code segment will initialize an element block with an ID of 10, write out the connectivity array, and write out the element attributes array:

```
int id, error, exoid, num_elem_in_blk, num_nodes_per_elem,
    *connect, num_attr;

float *attrib;

/* write element block parameters */
id = 10;
num_elem_in_blk = 2;
num_nodes_per_elem = 4;   /* elements are 4-node shells */
num_attr = 1;             /* one attribute per element */

error = ex_put_elem_block(exoid, id, "SHEL", num_elem_in_blk,
                          num_nodes_per_elem, num_attr);

/* write element connectivity */
connect = (int *)calloc(num_elem_in_blk*num_nodes_per_elem, sizeof(int));

/* fill connect with node numbers; nodes for first element*/
connect[0] = 1; connect[1] = 2; connect[2] = 3; connect[3] = 4;

/* nodes for second element */
connect[4] = 5; connect[5] = 6; connect[6] = 7; connect[7] = 8;

error = ex_put_elem_conn (exoid, id, connect);

/* write element block attributes */
attrib = (float *) calloc (num_attr*num_elem_in_blk, sizeof(float));

for (i=0, cnt=0; i < num_elem_in_blk; i++) {
   for (j=0; j < num_attr; j++, cnt++) {
      attrib[cnt] = 1.0;
   }
}

error = ex_put_elem_attr (exoid, id, attrib);
```

5.2.12 Read Element Block Parameters

The function ex_get_elem_block reads the parameters used to describe an element block. IDs of all element blocks stored can be determined by calling ex_get_elem_blk_ids.

In case of an error, ex_get_elem_block returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- element block with specified ID is not stored in the data file.

```
int ex_get_elem_block (int exoid,
                       int elem_blk_id,
                       char *elem_type,
                       int *num_elem_this_blk,
                       int *num_nodes_per_elem,
                       int *num_attr)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int elem_blk_id` [in]
: The element block ID.

`char* elem_type` [out]
: Returned element type of elements in the element block. The maximum length of this string is `MAX_STR_LENGTH`.

`int* num_elem_this_blk` [out]
: Returned number of elements in the element block.

`int* num_nodes_per_elem` [out]
: Returned number of nodes per element in the element block.

`int* num_attr` [out]
: Returned number of attributes per element in the element block.

As an example, the following code segment will read the parameters for the element block with an ID of 10 and read the connectivity and element attributes arrays from an open EXODUS file:

```
#include "exodusII.h"
int id, error, exoid, num_el_in_blk, num_nod_per_el, num_attr,
    *connect;
float *attrib;
char elem_type[MAX_STR_LENGTH+1];

/* read element block parameters */
id = 10;

error = ex_get_elem_block(exoid, id, elem_type, &num_el_in_blk,
                          &num_nod_per_elem, &num_attr);

/* read element connectivity */
connect = (int *) calloc(num_nod_per_el*num_el_in_blk,
                         sizeof(int));

error = ex_get_elem_conn(exoid, id, connect);

/* read element block attributes */
attrib = (float *) calloc (num_attr * num_el_in_blk, sizeof(float));
error = ex_get_elem_attr (exoid, id, attrib);
```

5.2.13 Read Element Blocks IDs

The function ex_get_elem_blk_ids reads the IDs of all of the element blocks. Memory must be allocated for the returned array of (num˙elem˙blk) IDs before this function is invoked. The required size(`num_elem_blk`) can be determined via a call to ex_inquire or ex_inquire_int .

In case of an error, ex_get_elem_blk_ids returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open

```
int ex_get_elem_blk_ids (int exoid,
                         int *elem_blk_ids)
```

`int exoid` [in]
EXODUS file ID returned from a previous call to ex_create or ex_open.

`int* elem_blk_ids` [out]
Returned array of the element blocks IDs. The order of the IDs in this array reflects the sequence that the element blocks were introduced into the file.

The following code segment reads all the element block IDs:

```
int error, exoid, *idelbs, num_elem_blk;
idelbs = (int *) calloc(num_elem_blk, sizeof(int));

error = ex_get_elem_blk_ids (exoid, idelbs);
```

5.2.14 Write Element Block Connectivity

The function ex_put_elem_conn writes the connectivity array for an element block. The function ex_put_elem_block must be invoked before this call is made.

In case of an error, ex_put_elem_conn returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file opened for read only.
- data file not initialized properly with call to ex_put_init .
- ex_put_elem_block was not called previously.

```
int ex_put_elem_conn (int exoid,
                      int elem_blk_id,
                      int *connect)
```

`int exoid` [in]
EXODUS file ID returned from a previous call to ex_create or ex_open.

`int elem_blk_id` [in]
The element block ID.

`int connect[num_elem_this_blk,num_nodes_per_elem]` [in]
The connectivity array; a list of nodes (internal node IDs; See Section 4.5) that define each element in the element block. The node index cycles faster than the element index.

Refer to the code example in Section **??** for an example of writing the connectivity array for an element block.

5.2.15 Read Element Block Connectivity

The function ex_get_elem_conn reads the connectivity array for an element block. Memory must be allocated for the connectivity array(`num_elem_this_blk` × `num_nodes_per_elem` in length) before this routine is called.

In case of an error, ex_get_elem_conn returns a negative number; a warning will return a positive number. Possible causes of errors include:

- an element block with the specified ID is not stored in the file.

```
int ex_get_elem_conn (int exoid,
                      int elem_blk_id,
                      int *connect)
```

`int exoid` [in]
EXODUS file ID returned from a previous call to ex_create or ex_open.

`int elem_blk_id` [in]
The element block ID.

`int connect[num_elem_this_blk,num_nodes_per_elem]` [out]
Returned connectivity array; a list of nodes (internal node IDs; See Section 4.5) that define each element. The node index cycles faster than the element index.

Refer to the code example in Section 5.2.12 for an example of reading the connectivity for an element block.

5.2.16 Write Element Block Attributes

The function ex_put_elem_attr writes the attributes for an element block. Each element in the element block must have the same number of attributes, so there are(`num_attr` × num˙elem˙this˙blk) attributes for each element block. The function ex_put_elem_block must be invoked before this call is made.

Because the attributes are floating point values, the application code must declare the array passed to be the appropriate type (“float” or “double”) to match the compute word size passed in ex_create or ex_open.

In case of an error, ex_put_elem_attr returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.
- data file not initialized properly with call to ex_put_init.
- ex_put_elem_block was not called previously for specified element block ID.
- ex_put_elem_block was called with 0 attributes specified.

```
int ex_put_elem_attr (int exoid,
                      int elem_blk_id,
                      void *attrib)
```

`int exoid` [in]
EXODUS file ID returned from a previous call to ex_create or ex_open.

`int elem_blk_id` [in]
The element block ID.

`void attrib[ num_elem_this_blk,num_attr]` [in]
The list of attributes for the element block. The `num_attr` index cycles faster.

Refer to the code example in Section 5.2.11 for an example of writing the attributes array for an element block.

5.2.17 Read Element Block Attributes

The function ex_get_elem_attr reads the attributes for an element block. Memory must be allocated for(`num_attr` × `num_elem_this_blk`) attributes before this routine is called.

Because the attributes are floating point values, the application code must declare the array passed to be the appropriate type ("float" or "double") to match the compute word size passed in ex_create or ex_open.

In case of an error, ex_get_elem_attr returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- invalid element block ID.
- a warning value is returned if no attributes are stored in the file.

```
int ex_get_elem_attr (int exoid,
                      int elem_blk_id,
                      void *attrib)
```

`int exoid` [in]
EXODUS file ID returned from a previous call to ex_create or ex_open.

`int elem_blk_id` [in]
The element block ID.

`void attrib[ num_elem_this_blk,num_attr]` [out]
Returned list of(`num_attr` × num˙elem˙this˙blk) attributes for the element block, with the `num_attr` index cycling faster.

Refer to the code example in Section 5.2.12 for an example of reading the element attributes for an element block.

5.2.18 Write Node Set Parameters

The function ex_put_node_set_param writes the node set ID, the number of nodes which describe a single node set, and the number of node set distribution factors for the node set.

In case of an error, ex_put_node_set_param returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.
- data file not initialized properly with call to ex_put_init .
- the number of node sets specified in the call to ex_put_init was zero or has been exceeded.
- a node set with the same ID has already been stored.
- the specified number of distribution factors is not zero and is not equal to the number of nodes.

```
int ex_put_node_set_param (int exoid,
                           int node_set_id,
                           int num_nodes_in_set,
                           int num_dist_in_set)
```

`int exoid` [in]
EXODUS file ID returned from a previous call to ex_create or ex_open.

`int node_set_id` [in]
The node set ID.

`int num_nodes_in_set` [in]
The number of nodes in the node set.

`int num_dist_in_set` [in]
The number of distribution factors in the node set. This should be either 0 (zero) for no factors, or should equal `num_nodes_in_set`.

The following code segment will write out a node set to an open EXODUS file:

```
int id, num_nodes_in_set, num_dist_in_set, error, exoid,
    *node_list;

float *dist_fact;

/* write node set parameters */
id = 20; num_nodes_in_set = 5; num_dist_in_set = 5;
error = ex_put_node_set_param(exoid, id, num_nodes_in_set,
                              num_dist_in_set);

/* write node set node list */
node_list = (int *) calloc (num_nodes_in_set, sizeof(int));
node_list[0] = 100; node_list[1] = 101; node_list[2] = 102;
node_list[3] = 103; node_list[4] = 104;

error = ex_put_node_set(exoid, id, node_list);

/* write node set distribution factors */
dist_fact = (float *) calloc (num_dist_in_set, sizeof(float));
dist_fact[0] = 1.0; dist_fact[1] = 2.0; dist_fact[2] = 3.0;
dist_fact[3] = 4.0; dist_fact[4] = 5.0;

error = ex_put_node_set_dist_fact(exoid, id, dist_fact);
```

5.2.19 Read Node Set Parameters

The function ex_get_node_set_param reads the number of nodes which describe a single node set and the number of distribution factors for the node set.

In case of an error, ex_get_node_set_param returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- a warning value is returned if no node sets are stored in the file.
- incorrect node set ID.

```
int ex_get_node_set_param (int exoid,
                           int node_set_id,
                           int *num_nodes_in_set,
                           int *num_dist_in_set)
```

`int exoid` [in]
EXODUS file ID returned from a previous call to ex_create or ex_open.

`int node_set_id` [in]
The node set ID.

`int* num_nodes_in_set` [out]
Returned number of nodes in the node set.

`int* num_dist_in_set` [out]
Returned number of distribution factors in the node set.

The following code segment will read a node set from an open EXODUS file:

```
int error, exoid, id, num_nodes_in_set, num_df_in_set, *node_list;

float *dist_fact;

/* read node set parameters */
id = 100;

error = ex_get_node_set_param(exoid, id, &num_nodes_in_set,
                              &num_df_in_set);

/* read node set node list */
node_list = (int *) calloc(num_nodes_in_set, sizeof(int));
error = ex_get_node_set(exoid, id, node_list);

/* read node set distribution factors */
if (num_df_in_set > 0) {
   dist_fact = (float *) calloc(num_nodes_in_set, sizeof(float));
   error = ex_get_node_set_dist_fact(exoid, id, dist_fact);
}
```

5.2.20 Write Node Set

The function ex_put_node_set writes the node list for a single node set. The function ex_put_node_set_param must be called before this routine is invoked.

In case of an error, ex_put_node_set returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.
- data file not initialized properly with call to ex_put_init .
- ex_put_node_set_param not called previously.

```
int ex_put_node_set (int exoid,
                     int node_set_id,
                     int *node_set_node_list)
```

`int exoid` [in]
EXODUS file ID returned from a previous call to ex_create or ex_open.

`int node_set_id` [in]
The node set ID.

`int* node_set_node_list` [in]

Array containing the node list for the node set. Internal node IDs are used in this list (See Section 4.5).

Refer to the description of ex_put_node_set_param for a sample code segment to write out a node set.

5.2.21 Write Node Set Distribution Factors

The function ex_put_node_set_dist_fact writes node set distribution factors for a single node set. The function ex_put_node_set_param must be called before this routine is invoked.

Because the distribution factors are floating point values, the application code must declare the array passed to be the appropriate type ("float" or "double") to match the compute word size passed in ex_create or ex_open.

In case of an error, ex_put_node_set_dist_fact returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.
- data file not initialized properly with call to ex_put_init.
- ex_put_node_set_param not called previously.
- a call to ex_put_node_set_param specified zero distribution factors.

```
int ex_put_node_set_dist_fact (int exoid,
                               int node_set_id,
                               void 8node_set_dist_fact)
```

`int exoid` [in]

EXODUS file ID returned from a previous call to ex_create or ex_open.

`int node_set_id` [in]

The node set ID.

`void* node_set_dist_fact` [in]

Array containing the distribution factors in the node set.

Refer to the description of ex_put_node_set_param for a sample code segment to write out the distribution factors for a node set.

5.2.22 Read Node Set Distribution Factors

The function ex_get_node_set_dist_fact returns the node set distribution factors for a single node set. Memory must be allocated for the list of distribution factors(`num_dist_in_set` in length) before this function is invoked.

Because the distribution factors are floating point values, the application code must declare the array passed to be the appropriate type ("float" or "double") to match the compute word size passed in ex_create or ex_open.

In case of an error, ex_get_node_set_dist_fact returns a negative number; a warning will return a positive number. Possible causes of errors include:

- a warning value is returned if no distribution factors were stored.

```
int ex_get_node_set_dist_fact (int exoid,
                               int node_set_id,
                               void 8node_set_dist_fact)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int node_set_id` [in]
: The node set ID.

`void* node_set_dist_fact` [out]
: Returned array containing the distribution factors in the node set.

Refer to the description of ex_get_node_set_param for a sample code segment to read a node set's distribution factors.

5.2.23 Read Node Sets IDs

The function ex_get_node_set_ids reads the IDs of all of the node sets. Memory must be allocated for the returned array of (num˙node˙sets) IDs before this function is invoked.

In case of an error, ex_get_node_set_ids returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- a warning value is returned if no node sets are stored in the file.

```
int ex_get_node_set_ids (int exoid,
                         int *node_set_ids)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int* node_set_ids` [out]
: Returned array of the node sets IDs. The order of the IDs in this array reflects the sequence the node sets were introduced into the file.

As an example, the following code will read all of the node set IDs from an open data file:

```c
int *ids, num_node_sets, error, exoid;

/* read node sets IDs */
ids = (int *) calloc(num_node_sets, sizeof(int));

error = ex_get_node_set_ids (exoid, ids);
```

5.2.24 Write Concatenated Node Sets

The function ex_put_concat_node_sets writes the node set ID's, node sets node count array, node sets distribution factor count array, node sets node list pointers array, node sets distribution factor pointer, node set node list, and node set distribution factors for all of the node sets. "Concatenated node sets" refers to the arrays required to define all of the node sets (ID array, counts arrays, pointers arrays, node list array, and distribution factors array) as described in Section 3.10 on page 11. Writing concatenated node sets is more efficient than writing individual node sets. See Appendix A for a discussion of efficiency issues.

Because the distribution factors are floating point values, the application code must declare the array passed to be the appropriate type ("float" or "double") to match the compute word size passed in ex_create or ex_open.

In case of an error, ex_put_concat_node_sets returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.
- data file not initialized properly with call to ex_put_init.
- the number of node sets specified in a call to ex_put_init was zero or has been exceeded.
- a node set with the same ID has already been stored.
- the number of distribution factors specified for one of the node sets is not zero and is not equal to the number of nodes in the same node set.

```c
int ex_put_concat_node_sets (int exoid,
                             int *node_set_ids,
                             int *num_nodes_per_set,
                             int *num_dist_per_set,
                             int *node_sets_node_index,
                             int *node_sets_dist_index,
                             int *node_sets_node_list,
                             void *node_sets_dist_fact)
```

`int exoid` [in]
EXODUS file ID returned from a previous call to ex_create or ex_open.

`int* node_set_ids` [in]
Array containing the node set ID for each set.

`int* num_nodes_per_set` [in]
: Array containing the number of nodes for each set.

`int* num_dist_per_set` [in]
: Array containing the number of distribution factors for each set.

`int* node_sets_node_index` [in]
: Array containing the indices into the `node_set_node_list` which are the locations of the first node for each set. These indices are 0-based.

`int* node_sets_dist_index` [in]
: Array containing the indices into the `node_set_dist_list` which are the locations of the first distribution factor for each set. These indices are 0-based.

`int* node_sets_node_list` [in]
: Array containing the nodes for all sets. Internal node IDs are used in this list (See Section 4.5).

`void* node_sets_dist_fact` [in]
: Array containing the distribution factors for all sets.

For example, the following code will write out two node sets in a concatenated format:

```
int ids[2], num_nodes_per_set[2], node_ind[2], node_list[8],
    num_df_per_set[2], df_ind[2], error, exoid;

float dist_fact[8];

ids[0] = 20; ids[1] = 21;
num_nodes_per_set[0] = 5; num_nodes_per_set[1] = 3;

node_ind[0] = 0; node_ind[1] = 5;

node_list[0] = 100; node_list[1] = 101; node_list[2] = 102;
node_list[3] = 103; node_list[4] = 104;
node_list[5] = 200; node_list[6] = 201; node_list[7] = 202;

num_df_per_set[0] = 5; num_df_per_set[1] = 3;

df_ind[0] = 0; df_ind[1] = 5;

dist_fact[0] = 1.0; dist_fact[1] = 2.0; dist_fact[2] = 3.0;
dist_fact[3] = 4.0; dist_fact[4] = 5.0;
dist_fact[5] = 1.1; dist_fact[6] = 2.1;
dist_fact[7] = 3.1;

error = ex_put_concat_node_sets (exoid, ids, num_nodes_per_set,
                                 num_df_per_set, node_ind, df_ind,
                                 node_list, dist_fact);
```

5.2.25 Read Concatenated Node Sets

The function ex_get_concat_node_sets reads the node set ID's, node set node count array, node set distribution factors count array, node set node pointers array, node set distribution factors pointer array, node set node list, and node set distribution factors for all of the node sets. "Concatenated node sets" refers to the arrays required to define all of the node sets (ID array, counts arrays, pointers arrays, node list array, and distribution factors array) as described in Section 3.10 on page 11.

Because the distribution factors are floating point values, the application code must declare the array passed to be the appropriate type ("float" or "double") to match the compute word size passed in ex_create or ex_open.

The length of each of the returned arrays can be determined by invoking ex_inquire or ex_inquire_int .

In case of an error, ex_get_concat_node_sets returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- a warning value is returned if no node sets are stored in the file.

```
int ex_get_concat_node_sets (int exoid,
                             int *node_set_ids,
                             int *num_nodes_per_set,
                             int *num_dist_per_set,
                             int *node_sets_node_index,
                             int *node_sets_dist_index,
                             int *node_sets_node_list,
                             void *node_sets_dist_fact)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int* node_set_ids` [out]
: Returned array containing the node set ID for each set.

`int* num_nodes_per_set` [out]
: Returned array containing the number of nodes for each set.

`int* num_dist_per_set` [out]
: Returned array containing the number of distribution factors for each set.

`int* node_sets_node index` [out]
: Returned array containing the indices into the `node_set_node_list` which are the locations of the first node for each set. These indices are 0-based.

`int* node_sets_dist_index` [out]
: Returned array containing the indices into the `node_set_dist_fact` which are the locations of the first distribution factor for each set. These indices are 0-based.

`int* node_sets_node_list` [out]

Returned array containing the nodes for all sets. Internal node IDs are used in this list (see Section 4.5).

`void* node_sets_dist_fact` [out]

Returned array containing the distribution factors for all sets.

As an example, the following code segment will read concatenated node sets:

```
#include "exodusII.h"

int error, exoid, num_node_sets, list_len, *ids,
    *num_nodes_per_set, *num_df_per_set, *node_ind,
    *df_ind, *node_list;

float *dist_fact

/* read concatenated node sets */
num_node_sets = ex_inquire_int(exoid, EX_INQ_NODE_SETS);

ids               = (int *) calloc(num_node_sets, sizeof(int));
num_nodes_per_set = (int *) calloc(num_node_sets, sizeof(int));
num_df_per_set    = (int *) calloc(num_node_sets, sizeof(int));
node_ind          = (int *) calloc(num_node_sets, sizeof(int));
df_ind            = (int *) calloc(num_node_sets, sizeof(int));

list_len = ex_inquire_int(exoid, EX_INQ_NS_NODE_LEN);
node_list = (int *) calloc(list_len, sizeof(int));

list_len = ex_inquire_int(exoid, EX_INQ_NS_DF_LEN);
dist_fact = (float *) calloc(list_len, sizeof(float));

error = ex_get_concat_node_sets (exoid, ids, num_nodes_per_set,
                                 num_df_per_set, node_ind, df_ind,
                                 node_list, dist_fact);
```

5.2.26 Write Side Set Parameters

The function ex_put_side_set_param writes the side set set ID and the number of sides (faces on 3D element types; edges on 2D element types) which describe a single side set, and the number of side set distribution factors on the side set. Because each side of a side set is completely defined by an element and a local side number, the number of sides is equal to the number of elements in a side set.

In case of an error, ex_put_side_set_param returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.
- data file not initialized properly with call to ex_put_init.
- the number of side sets specified in the call to ex_put_init was zero or has been exceeded.

- a side set with the same ID has already been stored.

```
int ex_put_side_set_param (int exoid,
                           int side_set_id,
                           int num_side_in_set,
                           int num_dist_fact_in_set)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int side_set_id` [in]
: The side set ID.

`int num_side_in_set` [in]
: The number of sides (faces or edges) in the side set.

`int num_dist_fact_in_set` [in]
: The number of distribution factors on the side set.

The following code segment will write a side set to an open EXODUS file:

```
int error, exoid, id, num_sides, num_df,
    elem_list[2], side_list[2];

float dist_fact[4];

/* write side set parameters */
id = 30;

num_sides = 2;
num_df    = 4;

error = ex_put_side_set_param (exoid, id, num_sides, num_df);

/* write side set element and side lists */
elem_list[0] = 1; elem_list[1] = 2;
side_list[0] = 1; side_list[1] = 1;

error = ex_put_side_set (exoid, id, elem_list, side_list);

/* write side set distribution factors */
dist_fact[0] = 30.0; dist_fact[1] = 30.1;
dist_fact[2] = 30.2; dist_fact[3] = 30.3;

error = ex_put_side_set_dist_fact (exoid, id, dist_fact);
```

5.2.27 Read Side Set Parameters

The function ex_get_side_set_param reads the number of sides (faces on 3D element types; edges on 2D element types) which describe a single side set, and the number of side set distribution factors on the side set.

In case of an error, ex_get_side_set_param returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- a warning value is returned if no side sets are stored in the file.
- incorrect side set ID.

```
int ex_get_side_set_param (int exoid,
                           int side_set_id,
                           int *num_side_in_set,
                           int *num_dist_fact_in_set)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int side_set_id` [in]
: The side set ID.

`int* num_side_in_set` [out]
: Returned number of sides (faces or edges) in the side set.

`int* num_dist_fact_in_set` [out]
: Returned number of distribution factors on the side set.

The following coding will read all of the side sets from an open EXODUS file:

```
int num_side_sets, error, exoid, num_sides_in_set, num_df_in_set,
    num_elem_in_set, *ids, *elem_list, *side_list, *ctr_list,
    *node_list;

float *dist_fact;

num_side_sets = ex_inquire_int(exoid, EX_INQ_SIDE_SETS);
ids = (int *) calloc(num_side_sets, sizeof(int));
error = ex_get_side_set_ids (exoid, ids);

for (i=0; i < num_side_sets; i++) {
   error = ex_get_side_set_param (exoid, ids[i], tab &num_sides_in_set,
                                  tab &num_df_in_set);

   num_elem_in_set = num_sides_in_set;
   elem_list = (int *) calloc(num_elem_in_set, sizeof(int));
   side_list = (int *) calloc(num_sides_in_set, sizeof(int));
   error = ex_get_side_set (exoid, ids[i], elem_list, side_list);

   if (num_df_in_set > 0) {
      /* get side set node list to correlate to dist factors */
      ctr_list  = (int *) calloc(num_elem_in_set, sizeof(int));
      node_list = (int *) calloc(num_df_in_set, sizeof(int));
      dist_fact = (float *) calloc(num_df_in_set, sizeof(float));
```

```
      error = ex_get_side_set_node_list (exoid, ids[i], ctr_list,
                                          node_list);

      error = ex_get_side_set_dist_fact (exoid, ids[i], tab dist_fact);
   }
}
```

5.2.28 Write Side Set

The function ex_put_side_set writes the side set element list and side set side (face on 3D element types; edge on 2D element types) list for a single side set. The routine ex_put_side_set_param must be called before this function is invoked.

In case of an error, ex_put_side_set returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.
- data file not initialized properly with call to ex_put_init .
- ex_put_side_set_param not called previously.

```
int ex_put_side_set (int exoid,
                     int side_set_id,
                     int *side_set_elem_list,
                     int *side_set_side_list)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int side_set_id` [in]
: The side set ID.

`int* side_set_elem_list` [in]
: Array containing the elements in the side set. Internal element IDs are used in this list (see Section 4.5).

`int* side_set_side_list` [in]
: Array containing the sides (faces or edges) in the side set.

For an example of a code segment to write a side set, refer to the description for ex_put_side_set_param.

5.2.29 Read Side Set

The function ex_get_side_set reads the side set element list and side set side (face for 3D element types; edge for 2D element types) list for a single side set. Memory must be allocated for the element list and side list (both are num˙side˙in˙set in length) before this function is invoked.

In case of an error, ex_get_side_set returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- a warning value is returned if no side sets are stored in the file.
- incorrect side set ID.

```
int ex_get_side_set (int exoid,
                     int side_set_id,
                     int *side_set_elem_list,
                     int *side_set_side_list)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int side_set_id` [in]
: The side set ID.

`int* side_set_elem_list` [out]
: Returned array containing the elements in the side set. Internal element IDs are used in this list (see Section 4.5).

`int* side_set_side_list` [out]
: Returned array containing the sides (faces or edges) in the side set.

For an example of code to read a side set from an EXODUS II file, refer to the description for ex_get_side_set_param.

5.2.30 Write Side Set Distribution Factors

The function ex_put_side_set_dist_fact writes side set distribution factors for a single side set. The routine ex_put_side_set_param must be called before this function is invoked.

Because the distribution factors are floating point values, the application code must declare the array passed to be the appropriate type ("float" or "double") to match the compute word size passed in ex_create or ex_open.

In case of an error, ex_put_side_set_dist_fact returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.
- data file not initialized properly with call to ex_put_init.
- ex_put_side_set_param not called previously.
- a call to ex_put_side_set_param specified zero distribution factors.

```
int ex_put_side_set_dist_fact (int exoid,
                               int side_set_id,
                               void *side_set_dist_fact)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int side_set_id` [in]
: The side set ID.

`void* side_set_dist_fact` [in]
: Array containing the distribution factors in the side set.

For an example of a code segment to write side set distribution factors, refer to the description for ex_put_side_set_param.

5.2.31 Read Side Set Distribution Factors

The function ex_get_side_set_dist_fact returns the side set distribution factors for a single side set. Memory must be allocated for the list of distribution factors (num˙dist˙fact˙in˙set in length) before this function is invoked.

Because the distribution factors are floating point values, the application code must declare the array passed to be the appropriate type ("float" or "double") to match the compute word size passed in ex_create or ex_open.

In case of an error, ex_get_side_set_dist_fact returns a negative number; a warning will return a positive number. Possible causes of errors include:

- a warning value is returned if no distribution factors were stored.

```
int ex_get_side_set_dist_fact (int exoid,
                               int side_set_id,
                               void *side_set_dist_fact)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int side_set_id` [in]
: The side set ID.

`void* side_set_dist_fact` [out]
: Returned array containing the distribution factors in the side set.

For an example of code to read side set distribution factors from an EXODUS file, refer to the description for ex_get_side_set_param.

5.2.32 Read Side Sets IDs

The function ex_get_side_set_ids reads the IDs of all of the side sets. Memory must be allocated for the returned array of (num_side_sets) IDs before this function is invoked.

In case of an error, ex_get_side_set_ids returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- a warning value is returned if no side sets are stored in the file.

```
int ex_get_side_set_ids (int exoid,
                         int *side_set_ids)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int* side_set_ids` [out]
: Returned array of the side set IDs. The order of the IDs in this array reflects the sequence the side sets were introduced into the file.

For an example of code to read side set IDs from an EXODUS II file, refer to the description for ex_get_side_set_param.

5.2.33 Read Side Set Node List

The function ex_get_side_set_node_list returns a node count array and a list of nodes on a single side set. With the 2.0 and later versions of the database, this node list isn't stored directly but can be derived from the element number in the side set element list, local side number in the side set side list, and the element connectivity array. The application program must allocate memory for the node count array and node list.

There is a one-to-one mapping (i.e., same order – as shown in Table 2, "Side Set Node Ordering," on page 16 – and same number) between the nodes in the side set node list and the side set distribution factors. Thus, if distribution factors are stored for the side set of interest, the required size for the node list is the number of distribution factors returned by ex_get_side_set_param. If distribution factors are not stored for the side set, the application program must allocate a maximum size anticipated for the node list. This would be the product of the number of elements in the side set and the maximum number of nodes per side for all types of elements in the model, since side sets can span across different element types.

The length of the node count array is the length of the side set element list. For each entry in the side set element list, there is an entry in the side set side list, designating a local side number. The corresponding entry in the node count array is the number of nodes which define the particular side. In conjunction with the side set node list, this node count array gives an unambiguous nodal description of the side set.

In case of an error, ex_get_side_set_node_list returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- a warning value is returned if no side sets are stored in the file.
- incorrect side set ID.

```
int ex_get_side_set_node_list (int exoid,
                               int side_set_id,
                               int *side_set_node_cnt_list,
                               int *side_set_node_list)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int side_set_id` [in]
: The side set ID.

`int* side_set_node_cnt_list` [out]
: Returned array containing the number of nodes for each side (face in 3D, edge in 2D) in the side set.

`int* side_set_node_list` [out]
: Returned array containing a list of nodes on the side set. Internal node IDs are used in this list (see Section 3.5 4.5).

For an example of code to read a side set node list from an EXODUS file, refer to the description for ex_get_side_set_param.

5.2.34 Write Concatenated Side Sets

The function ex_put_concat_side_sets writes the side set IDs, side set element count array, side set distribution factor count array, side set element pointers array, side set distribution factors pointers array, side set element list, side set side list, and side set distribution factors. "Concatenated side sets" refers to the arrays needed to define all of the side sets (ID array, side counts array, node counts array, element pointer array, node pointer array, element list, node list, and distribution factors array) as described in Section 3.12 on page 15. Writing concatenated side sets is more efficient than writing individual side sets. See Appendix A for a discussion of efficiency issues.

Because the distribution factors are floating point values, the application code must declare the array passed to be the appropriate type ("float" or "double") to match the compute word size passed in ex_create or ex_open.

In case of an error, ex_put_concat_side_sets returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.
- data file not initialized properly with call to ex_put_init.

- the number of side sets specified in a call to ex_put_init was zero or has been exceeded.
- a side set with the same ID has already been stored.

```
int ex_put_concat_side_sets (int exoid,
                             int *side_sets_ids,
                             int *num_side_per_set,
                             int *num_dist_per_set,
                             int *side_sets_elem_index,
                             int *side_sets_dist_index,
                             int *side_sets_elem_list,
                             int *side_sets_side_list,
                             void *side_sets_dist_fact)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int* side_sets_ids` [in]
: Array containing the side set ID for each set.

`int* num_side_per_set` [in]
: Array containing the number of sides for each set.

`int* num_dist_per_set` [in]
: Array containing the number of distribution factors for each set.

`int* side_sets_elem_index` [in]
: Array containing the indices into the `side_sets_elem_list` which are the locations of the first element for each set. These indices are 0-based.

`int* side_sets_dist_index` [in]
: Array containing the indices into the `side_sets_dist_fact` which are the locations of the first distribution factor for each set. These indices are 0-based.

`int* side_sets_elem_list` [in]
: Array containing the elements for all side sets. Internal element IDs are used in this list (see Section 4.6).

`int* side_sets_side_list` [in]
: Array containing the sides for all side sets.

`void* side_sets_dist_fact` [in]
: Array containing the distribution factors for all side sets.

The following coding will write out two side sets in a concatenated format:

```
int error, exoid, ids[2], num_side_per_set[2], elem_ind[2],
    num_df_per_set[2], df_ind[2], elem_list[4], side_list[4];
```

```

float dist_fact[8];

/* write concatenated side sets */
ids[0] = 30;
ids[1] = 31;

num_side_per_set[0] = 2;
num_side_per_set[1] = 2;

elem_ind[0] = 0;
elem_ind[1] = 2;

num_df_per_set[0] = 4;
num_df_per_set[1] = 4;

df_ind[0] = 0;
df_ind[1] = 4;

/* side set #1 */
elem_list[0] = 2; elem_list[1] = 2;
side_list[0] = 2; side_list[1] = 1;

dist_fact[0] = 30.0; dist_fact[1] = 30.1;
dist_fact[2] = 30.2; dist_fact[3] = 30.3;

/* side set #2 */
elem_list[2] = 1; elem_list[3] = 2;
side_list[2] = 4; side_list[3] = 3;

dist_fact[4] = 31.0; dist_fact[5] = 31.1;
dist_fact[6] = 31.2; dist_fact[7] = 31.3;

error = ex_put_concat_side_sets (exoid, ids, num_side_per_set,
                                 num_df_per_set, elem_ind, df_ind,
                                 elem_list, side_list, dist_fact);
```

5.2.35 Read Concatenated Side Sets

The function ex_get_concat_side_sets reads the side set IDs, side set element count array, side set distribution factors count array, side set element pointers array, side set distribution factors pointers array, side set element list, side set side list, and side set distribution factors. "Concatenated side sets" refers to the arrays needed to define all of the side sets (ID array, side counts array, node counts array, element pointer array, node pointer array, element list, node list, and distribution factors array) as described in Section 3.12 on page 15.

Because the distribution factors are floating point values, the application code must declare the array passed to be the appropriate type ("float" or "double") to match the compute word size passed in ex_create or ex_open.

The length of each of the returned arrays can be determined by invoking ex_inquire or ex_inquire_int .

In case of an error, ex_get_concat_side_sets returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- a warning value is returned if no side sets are stored in the file.

```
int ex_get_concat_side_sets (int exoid,
                             int *side_set_ids,
                             int *num_side_per_set,
                             int *num_dist_per_set,
                             int *side_sets_elem_index,
                             int *side_sets_dist_index,
                             int *side_sets_elem_list,
                             int *side_sets_side_list,
                             void *side_sets_dist_fact)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int* side_set_ids` [out]
: Returned array containing the side set ID for each set.

`int* num_side_per_set` [out]
: Returned array containing the number of sides for each set.

`int* num_dist_per_set` [out]
: Returned array containing the number of distribution factors for each set.

`int* side_sets_elem_index` [out]
: Returned array containing the indices into the side˙sets˙elem˙list which are the locations of the first element for each set. These indices are 0-based.

`int* side_sets_dist_index` [out]
: Returned array containing the indices into the `side_sets_dist_fact` array which are the locations of the first distribution factor for each set. These indices are 0-based.

`int* side_sets_elem_list` [out]
: Returned array containing the elements for all side sets. Internal element IDs are used in this list (see Section 4.6).

`int* side_sets_side_list` [out]
: Returned array containing the sides for all side sets.

`void* side_sets_dist_fact` [out]
: Returned array containing the distribution factors for all side sets.

The following code segment will return in concatenated format all the side sets stored in an EXODUS file:

```
#include "exodusII.h"
```

```
int error, exoid, num_ss, elem_list_len, df_list_len,
    *ids, *side_list, *num_side_per_set, *num_df_per_set,
    *elem_ind, *df_ind, *elem_list;

float *dist_fact;

num_ss = ex_inquire_int(exoid, EX_INQ_SIDE_SETS);

if (num_ss > 0) {
   elem_list_len = ex_inquire_int(exoid, EX_INQ_SS_ELEM_LEN);
   df_list_len   = ex_inquire_int(exoid, EX_INQ_SS_DF_LEN);

   /* read concatenated side sets */
   ids = (int *) calloc(num_ss, sizeof(int));
   num_side_per_set = (int *) calloc(num_ss, sizeof(int));
   num_df_per_set   = (int *) calloc(num_ss, sizeof(int));
   elem_ind         = (int *) calloc(num_ss, sizeof(int));
   df_ind           = (int *) calloc(num_ss, sizeof(int));
   elem_list        = (int *) calloc(elem_list_len, sizeof(int));
   side_list        = (int *) calloc(elem_list_len, sizeof(int));
   dist_fact        = (float *) calloc(df_list_len, sizeof(float));

   error = ex_get_concat_side_sets (exoid, ids, num_side_per_set,
                                    num_df_per_set, elem_ind, df_ind,
                                    elem_list, side_list,dist_fact);
}
```

5.2.36 Convert Side Set Nodes to Sides

The function ex_cvt_nodes_to_sides is used to convert a side set node list to a side set side list. This routine is provided for application programs that utilize side sets defined by nodes (as was done previous to release 2.0) rather than local faces or edges. The application program must allocate memory for the returned array of sides. The length of this array is the same as the length of the concatenated side sets element list, which can be determined with a call to ex_inquire or ex_inquire_int .

In case of an error, ex_cvt_nodes_to_sides returns a negative number; a warning will return a positive number. Possible causes of errors include:

- a warning value is returned if no side sets are stored in the file.
- because the faces of a wedge require a different number of nodes to describe them (quadrilateral vs. triangular faces), the function will abort with a fatal return code if a wedge is encountered in the side set element list.

```
int ex_cvt_nodes_to_sides (int exoid,
                           int *num_side_per_set,
                           int *num_nodes_per_set,
                           int *side_sets_elem_index,
                           int *side_sets_node_index,
                           int *side_sets_elem_list,
                           int *side_sets_node_list,
                           int *side_sets_side_list)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int* num_side_per_set` [in]
: Array containing the number of sides for each set. The number of sides is equal to the number of elements for each set.

`int* num_nodes_per_set` [in]
: Array containing the number of nodes for each set.

`int* side_sets_elem_index` [in]
: Array containing indices into the **side_sets_elem_list** which are the locations of the first element for each set. These indices are 0-based.

`int* side_sets_node_index` [in]
: Array containing indices into the **side_sets_node_list** which are the locations of the first node for each set. These indices are 0-based.

`int* side_sets_elem_list` [in]
: Array containing the elements for all side sets. Internal element IDs are used in this list (see Section 4.6).

`int* side_sets_node_list` [in]
: Array containing the nodes for all side sets. Internal node IDs are used in this list (see Section 4.5).

`int* side_sets_side_list` [out]
: Returned array containing the sides for all side sets.

The following code segment will convert side sets described by nodes to side sets described by local side numbers:

```
int error, exoid, ids[2], num_side_per_set[2],
    num_nodes_per_set[2], elem_ind[2], node_ind[2],
    elem_list[4], node_list[8], el_lst_len, *side_list;

ids[0] = 30              ; ids[1]   = 31;
num_side_per_set[0]  = 2; num_side_per_set[1] = 2;
num_nodes_per_set[0] = 4; num_nodes_per_set[1] = 4;

```

```
elem_ind[0] = 0; elem_ind[1] = 2;
node_ind[0] = 0; node_ind[1] = 4;

/* side set #1 */
elem_list[0] = 2; elem_list[1] = 2;
node_list[0] = 8; node_list[1] = 5;
node_list[2] = 6; node_list[3] = 7;

/* side set #2 */
elem_list[2] = 1; elem_list[3] = 2;
node_list[4] = 2; node_list[5] = 3;
node_list[6] = 7; node_list[7] = 8;

el_lst_len = ex_inquire_int(exoid, EX_INQ_SS_ELEM_LEN);

/* side set element list is same length as side list */
side_list = (int *) calloc (el_lst_len, sizeof(int));

ex_cvt_nodes_to_sides(exoid, num_side_per_set, num_nodes_per_set,
                      elem_ind, node_ind, elem_list,
                      node_list, side_list);
```

5.2.37 Write Property Arrays Names

The function ex_put_prop_names writes object property names and allocates space for object property arrays used to assign integer properties to element blocks, node sets, or side sets. The property arrays are initialized to zero (0). Although this function is optional, since ex_put_prop will allocate space within the data file if it hasn't been previously allocated, it is more efficient to use ex_put_prop_names if there is more than one property to store. See Appendix A for a discussion of efficiency issues.

In case of an error, ex_put_prop_names returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.
- data file not initialized properly with call to ex_put_init.
- invalid object type specified.
- no object of the specified type is stored in the file.

```
int ex_put_prop_names (int exoid,
                       ex_entity_type obj_type,
                       int num_props,
                       char **prop_names)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`ex_entity_type obj_typ` [in]

Type of object; use one of the following options:

EX_NODE_SET	Node Set entity type
EX_EDGE_BLOCK	Edge Block entity type
EX_EDGE_SET	Edge Set entity type
EX_FACE_BLOCK	Face Block entity type
EX_FACE_SET	Face Set entity type
EX_ELEM_BLOCK	Element Block entity type
EX_ELEM_SET	Element Set entity type
EX_SIDE_SET	Side Set entity type
EX_ELEM_MAP	Element Map entity type
EX_NODE_MAP	Node Map entity type
EX_EDGE_MAP	Edge Map entity type
EX_FACE_MAP	Face Map entity type

`int num_props` [in]

The number of integer properties to be assigned to all of the objects of the type specified (element blocks, node sets, or side sets).

`char** prop_names` [in]

Array containing `num_props` names (of maximum length of `MAX_STR_LENGTH`) of properties to be stored.

For instance, suppose a user wanted to assign the 1st, 3rd, and 5th element blocks (those element blocks stored 1st, 3rd, and 5th, regardless of their ID) to a group (property) called "TOP", and the 2nd, 3rd, and 4th element blocks to a group called "LSIDE". This could be accomplished with the following code:

```
#include "exodusII.h";

char* prop_names[2];
int top_part[]   = {1,0,1,0,1};
int lside_part[] = {0,1,1,1,0};

int id[] = {10, 20, 30, 40, 50};

prop_names[0] = ``TOP'';
prop_names[1] = ``LSIDE'';

/* This call to ex_put_prop_names is optional, but more efficient */
ex_put_prop_names (exoid, EX_ELEM_BLOCK, 2, prop_names);

/* The property values can be output individually thus */
for (i=0; i < 5; i++) {
   ex_put_prop (exoid, EX_ELEM_BLOCK, id[i], prop_names[0],
                top_part[i]);

   ex_put_prop (exoid, EX_ELEM_BLOCK, id[i], prop_names[1],
                lside_part[i]);
}

/* Alternatively, the values can be output as an array thus*/
ex_put_prop_array (exoid, EX_ELEM_BLOCK, prop_names[0],
```

```
                        top_part);

ex_put_prop_array (exoid, EX_ELEM_BLOCK, prop_names[1],
                        lside_part);
```

5.2.38 Read Property Arrays Names

The function ex_get_prop_names returns names of integer properties stored for an element block, node set, or side set. The number of properties (needed to allocate space for the property names) can be obtained via a call to ex_inquire or ex_inquire_int .

In case of an error, ex_get_prop_names returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- invalid object type specified.

```
int ex_get_prop_names (int exoid,
                       ex_entity_type obj_type,
                       char **prop_names)
```

`int exoid` [in]

EXODUS file ID returned from a previous call to ex_create or ex_open.

`ex_entity_type obj_type` [in]

Type of object; use one of the following options:

`EX_NODE_SET`	Node Set entity type
`EX_EDGE_BLOCK`	Edge Block entity type
`EX_EDGE_SET`	Edge Set entity type
`EX_FACE_BLOCK`	Face Block entity type
`EX_FACE_SET`	Face Set entity type
`EX_ELEM_BLOCK`	Element Block entity type
`EX_ELEM_SET`	Element Set entity type
`EX_SIDE_SET`	Side Set entity type
`EX_ELEM_MAP`	Element Map entity type
`EX_NODE_MAP`	Node Map entity type
`EX_EDGE_MAP`	Edge Map entity type
`EX_FACE_MAP`	Face Map entity type

`char** prop_names` [out]

eturned array containing `num_props` (obtained from call to ex_inquire or ex_inquire_int) names (of maximum length `MAX_STR_LENGTH`) of properties to be stored. "ID", a reserved property name, will be the first name in the array.

As an example, the following code segment reads in properties assigned to node sets:

```
#include "exodusII.h";
int error, exoid, num_props, *prop_values;
```

```
char *prop_names[MAX_PROPS];

/* read node set properties */
num_props = ex_inquire_int(exoid, EX_INQ_NS_PROP);

for (i=0; i < num_props; i++) {
   prop_names[i] = (char *) malloc ((MAX_STR_LENGTH+1), sizeof(char));
   prop_values = (int *) malloc (num_node_sets, sizeof(int));
}

error = ex_get_prop_names(exoid,EX_NODE_SET,prop_names);

for (i=0; i < num_props; i++) {
   error = ex_get_prop_array(exoid, EX_NODE_SET, prop_names[i],
                             prop_values);
}
```

5.2.39 Write Object Property

The function ex_put_prop stores an integer object property value to a single element block, node set, or side set. Although it is not necessary to invoke ex_put_prop_names, since ex_put_prop will allocate space within the data file if it hasn't been previously allocated, it is more efficient to use ex_put_prop_names if there is more than one property to store. See Appendix A for a discussion of efficiency issues.

It should be noted that the interpretation of the values of the integers stored as properties is left to the application code. In general, a zero (0) means the object does not have the specified property (or is not in the specified group); a nonzero value means the object does have the specified property. When space is allocated for the properties using ex_put_prop_names or ex_put_prop, the properties are initialized to zero (0).

Because the ID of an element block, node set, or side set is just another property (named "ID"), this routine can be used to change the value of an ID. This feature must be used with caution, though, because changing the ID of an object to the ID of another object of the same type (element block, node set, or side set) would cause two objects to have the same ID, and thus only the first would be accessible. Therefore, ex_put_prop issues a warning if a user attempts to give two objects the same ID.

In case of an error, ex_put_prop returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.
- data file not initialized properly with call to ex_put_init.
- invalid object type specified.
- a warning is issued if a user attempts to change the ID of an object to the ID of an existing object of the same type.

```
int ex_put_prop (int exoid,
                 ex_entity_type obj_type,
                 int obj_id,
                 char *prop_name,
                 int value)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`ex_entity_type obj_type` [in]
: Type of object; use one of the following options:

EX_NODE_SET	Node Set entity type
EX_EDGE_BLOCK	Edge Block entity type
EX_EDGE_SET	Edge Set entity type
EX_FACE_BLOCK	Face Block entity type
EX_FACE_SET	Face Set entity type
EX_ELEM_BLOCK	Element Block entity type
EX_ELEM_SET	Element Set entity type
EX_SIDE_SET	Side Set entity type
EX_ELEM_MAP	Element Map entity type
EX_NODE_MAP	Node Map entity type
EX_EDGE_MAP	Edge Map entity type
EX_FACE_MAP	Face Map entity type

`int obj_id` [in]
: The element block, node set, or side set ID.

`char* prop_name` [in]
: The name of the property for which the value will be stored. Maximum length of this string is `MAX_STR_LENGTH`.

`int value` [in]
: he value of the property.

For an example of code to write out an object property, refer to the description for ex_put_prop_names.

5.2.40 Read Object Property

The function ex_get_prop reads an integer object property value stored for a single element block, node set, or side set.

In case of an error, ex_get_prop returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- invalid object type specified.
- a warning value is returned if a property with the specified name is not found.

```
int ex_get_prop (int exoid,
                 ex_entity_type obj_type,
                 int obj_id,
                 char *prop_name,
                 int value)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`ex_entity_type obj_type` [in]
: Type of object; use one of the following options:

EX_NODE_SET	Node Set entity type
EX_EDGE_BLOCK	Edge Block entity type
EX_EDGE_SET	Edge Set entity type
EX_FACE_BLOCK	Face Block entity type
EX_FACE_SET	Face Set entity type
EX_ELEM_BLOCK	Element Block entity type
EX_ELEM_SET	Element Set entity type
EX_SIDE_SET	Side Set entity type
EX_ELEM_MAP	Element Map entity type
EX_NODE_MAP	Node Map entity type
EX_EDGE_MAP	Edge Map entity type
EX_FACE_MAP	Face Map entity type

`int obj_id` [in]
: The element block, node set, or side set ID.

`char* prop_name` [in]
: The name of the property (maximum length is `MAX_STR_LENGTH`) for which the value is desired.

`int* value` [out]
: Returned value of the property.

For an example of code to read an object property, refer to the description for ex_get_prop_names.

5.2.41 Write Object Property Array

The function ex_put_prop_array stores an array of (num˙elem˙blk, `num_node_sets`, or `num_side_sets`) integer property values for all element blocks, node sets, or side sets. The order of the values in the array must correspond to the order in which the element blocks, node sets, or side sets were introduced into the file. For instance, if the parameters for element block with ID 20 were written to a file (via ex_put_elem_block), and then parameters for element block with ID 10, followed by the parameters for element block with ID 30, the first, second, and third elements in the property array would correspond to element block 20, element block 10, and element block 30, respectively.

One should note that this same functionality (writing properties to multiple objects) can be accomplished with multiple calls to ex_put_prop.

Although it is not necessary to invoke ex_put_prop_names, since ex_put_prop_array will allocate space within the data file if it hasn't been previously allocated, it is more efficient to use ex_put_prop_names if there is more than one property to store. See Appendix A for a discussion of efficiency issues.

In case of an error, ex_put_prop_array returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.
- data file not initialized properly with call to ex_put_init.
- invalid object type specified.

```
int ex_put_prop_array (int exoid,
                       ex_entity_type obj_type,
                       char *prop_name,
                       int *values)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`ex_entity_type obj_type` [in]
: Type of object; use one of the following options:

EX_NODE_SET	Node Set entity type
EX_EDGE_BLOCK	Edge Block entity type
EX_EDGE_SET	Edge Set entity type
EX_FACE_BLOCK	Face Block entity type
EX_FACE_SET	Face Set entity type
EX_ELEM_BLOCK	Element Block entity type
EX_ELEM_SET	Element Set entity type
EX_SIDE_SET	Side Set entity type
EX_ELEM_MAP	Element Map entity type
EX_NODE_MAP	Node Map entity type
EX_EDGE_MAP	Edge Map entity type
EX_FACE_MAP	Face Map entity type

`char* prop_name` [in]
: The name of the property for which the values will be stored. Maximum length of this string is `MAX_STR_LENGTH`.

`int* values` [in]
: An array of property values.

For an example of code to write an array of object properties, refer to the description for ex_put_prop_names.

5.2.42 Read Object Property Array

The function ex_get_prop_array reads an array of integer property values for all element blocks, node sets, or side sets. The order of the values in the array correspond to the order in which the element blocks, node sets, or side sets were introduced into the file. Before this function is invoked, memory must be allocated for the returned array of(`num_elem_blk`, `num_node_sets`, or num˙side˙sets) integer values.

This function can be used in place of ex_get_elem_blk_ids, ex_get_node_set_ids, and ex_get_side_set_ids to get element block, node set, and side set IDs, respectively, by requesting the property name "ID." One should also note that this same function can be accomplished with multiple calls to ex_get_prop.

In case of an error, ex_get_prop_array returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- invalid object type specified.
- a warning value is returned if a property with the specified name is not found.

```
int ex_get_prop_array (int exoid,
                        ex_entity_type obj_type,
                        char *prop_name,
                        int *values)
```

`int exoid` [in]

EXODUS file ID returned from a previous call to ex_create or ex_open.

`ex_entity_type obj_type` [in]

Type of object; use one of the following options:

`EX_NODE_SET`	Node Set entity type
`EX_EDGE_BLOCK`	Edge Block entity type
`EX_EDGE_SET`	Edge Set entity type
`EX_FACE_BLOCK`	Face Block entity type
`EX_FACE_SET`	Face Set entity type
`EX_ELEM_BLOCK`	Element Block entity type
`EX_ELEM_SET`	Element Set entity type
`EX_SIDE_SET`	Side Set entity type
`EX_ELEM_MAP`	Element Map entity type
`EX_NODE_MAP`	Node Map entity type
`EX_EDGE_MAP`	Edge Map entity type
`EX_FACE_MAP`	Face Map entity type

`char* prop_name` [in]

The name of the property (maximum length of `MAX_STR_LENGTH`) for which the values are desired.

`int* values` [out]

Returned array of property values.

For an example of code to read an array of object properties, refer to the description for ex_get_prop_names.

5.3 Results Data

This section describes functions which read and write analysis results data and related entities. These include results variables (global, elemental, and nodal), element variable truth table, and simulation times.

5.3.1 Write Results Variables Parameters

The function ex_put_variable_param writes the number of global, nodal, or element variables that will be written to the database.

In case of an error, ex_put_variable_param returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.
- invalid variable type specified.
- data file not initialized properly with call to ex_put_init .
- this routine has already been called with the same variable type; redefining the number of variables is not allowed.
- a warning value is returned if the number of variables is specified as zero.

```
int ex_put_variable_param (int exoid,
                           ex_entity_type var_type,
                           int num_vars)
```

`int exoid` [in]
EXODUS file ID returned from a previous call to ex_create or ex_open.

`ex_entity_type var_type` [in]
Variable indicating the type of variable which is described. Use one of the following options:

`EX_GLOBAL`	Global entity type
`EX_NODAL`	Nodal entity type
`EX_NODE_SET`	Node Set entity type
`EX_EDGE_BLOCK`	Edge Block entity type
`EX_EDGE_SET`	Edge Set entity type
`EX_FACE_BLOCK`	Face Block entity type
`EX_FACE_SET`	Face Set entity type
`EX_ELEM_BLOCK`	Element Block entity type
`EX_ELEM_SET`	Element Set entity type
`EX_SIDE_SET`	Side Set entity type

`int num_vars` [in]
The number of `var_type` variables that will be written to the database.

For example, the following code segment initializes the data file to store global variables:

```
int num_glo_vars, error, exoid;

/* write results variables parameters */
num_glo_vars = 3;

error = ex_put_variable_param (exoid, EX_GLOBAL, num_glo_vars);
```

5.3.2 Read Results Variables Parameters

The function ex_get_variable_param reads the number of global, nodal, or element variables stored in the database.

In case of an error, ex_get_variable_param returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- invalid variable type specified.

```
int ex_get_variable_param (int exoid,
                           ex_entity_typevar_type,
                           int *num_vars)
```

`int exoid` [in]

EXODUS file ID returned from a previous call to ex_create or ex_open.

`ex_entity_type var_type` [in]

Variable indicating the type of variable which is described. Use one of the following options:

EX_GLOBAL	Global entity type
EX_NODAL	Nodal entity type
EX_NODE_SET	Node Set entity type
EX_EDGE_BLOCK	Edge Block entity type
EX_EDGE_SET	Edge Set entity type
EX_FACE_BLOCK	Face Block entity type
EX_FACE_SET	Face Set entity type
EX_ELEM_BLOCK	Element Block entity type
EX_ELEM_SET	Element Set entity type
EX_SIDE_SET	Side Set entity type

`int* num_vars` [out]

Returned number of `var_type` variables that are stored in the database.

As an example, the following coding will determine the number of global variables stored in the data file:

```
int num_glo_vars, error, exoid;

/* read global variables parameters */
error = ex_get_variable_param(exoid, EX_GLOBAL, &num_glo_vars);
```

5.3.3 Write Results Variables Names

The function ex_put_variable_names writes the names of the results variables to the database. The names are `MAX_STR_LENGTH`-characters in length. The function ex_put_variable_param must be called before this function is invoked.

In case of an error, ex_put_variable_names returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file not initialized properly with call to ex_put_init .
- invalid variable type specified.
- ex_put_variable_param was not called previously or was called with zero variables of the specified type.
- ex_put_variable_names has been called previously for the specified variable type.

```
int ex_put_variable_names (int exoid,
                           ex_entity_type var_type,
                           int num_vars,
                           char **var_names[])
```

`int exoid` [in]

EXODUS file ID returned from a previous call to ex_create or ex_open.

`ex_entity_type var_type` [in]

Variable indicating the type of variable which is described. Use one of the following options:

`EX_GLOBAL`	Global entity type
`EX_NODAL`	Nodal entity type
`EX_NODE_SET`	Node Set entity type
`EX_EDGE_BLOCK`	Edge Block entity type
`EX_EDGE_SET`	Edge Set entity type
`EX_FACE_BLOCK`	Face Block entity type
`EX_FACE_SET`	Face Set entity type
`EX_ELEM_BLOCK`	Element Block entity type
`EX_ELEM_SET`	Element Set entity type
`EX_SIDE_SET`	Side Set entity type

`int num_vars` [in]

The number of `var_type` variables that will be written to the database.

`char** var_names` [in]

Array of pointers to `num_vars` variable names.

The following coding will write out the names associated with the nodal variables:

```
int num_nod_vars, error, exoid;
char *var_names[2];
```

```
/* write results variables parameters and names */
num_nod_vars = 2;

var_names[0] = "disx";
var_names[1] = "disy";

error = ex_put_variable_param (exoid, EX_NODAL, num_nod_vars);
error = ex_put_variable_names (exoid, EX_NODAL, num_nod_vars, var_names);
```

5.3.4 Read Results Variable Names

The function ex_get_variable_names reads the names of the results variables from the database. Memory must be allocated for the name array before this function is invoked. The names are `MAX_STR_LENGTH`-characters in length.

In case of an error, ex_get_variable_names returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- invalid variable type specified.
- a warning value is returned if no variables of the specified type are stored in the file.

```
int ex_get_variable_names (int exoid,
                           ex_entity_type var_type,
                           int num_vars,
                           char *var_names[])
```

`int exoid` [in]

EXODUS file ID returned from a previous call to ex_create or ex_open.

`ex_entity_type var_type` [in]

Variable indicating the type of variable which is described. Use one of the following options:

`EX_GLOBAL`	Global entity type
`EX_NODAL`	Nodal entity type
`EX_NODE_SET`	Node Set entity type
`EX_EDGE_BLOCK`	Edge Block entity type
`EX_EDGE_SET`	Edge Set entity type
`EX_FACE_BLOCK`	Face Block entity type
`EX_FACE_SET`	Face Set entity type
`EX_ELEM_BLOCK`	Element Block entity type
`EX_ELEM_SET`	Element Set entity type
`EX_SIDE_SET`	Side Set entity type

`int num_vars` [in]

The number of `var_type` variables that will be read from the database.

`char** var_names` [out]

Returned array of pointers to `num_vars` variable names.

As an example, the following code segment will read the names of the nodal variables stored in the data file:

```
#include "exodusII.h"
int error, exoid, num_nod_vars;
char *var_names[10];

/* read nodal variables parameters and names */
error = ex_get_variable_param(exoid, EX_NODAL, &num_nod_vars);
for (i=0; i < num_nod_vars; i++) {
   var_names[i] = (char *) calloc ((MAX_STR_LENGTH+1), sizeof(char));
}
error = ex_get_variable_names(exoid, EX_NODAL, num_nod_vars, var_names);
```

5.3.5 Write Time Value for a Time Step

The function ex_put_time writes the time value for a specified time step.

Because time values are floating point values, the application code must declare the array passed to be the appropriate type ("float" or "double") to match the compute word size passed in ex_create or ex_open.

In case of an error, ex_put_time returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.

```
int ex_put_time (int exoid,
                 int time_step,
                 void *time_value)
```

`int exoid` [in]
EXODUS file ID returned from a previous call to ex_create or ex_open.

`int time_step` [in]
The time step number. This is essentially a counter that is incremented only when results variables are output to the data file. The first time step is 1.

`void* time_value` [in]
The time at the specified time step.

The following code segment will write out the simulation time value at simulation time step n:

```
int error, exoid, n;
float time_value;

/* write time value */
error = ex_put_time (exoid, n, &time_value);
```

5.3.6 Read Time Value for a Time Step

The function ex_get_time reads the time value for a specified time step.

Because time values are floating point values, the application code must declare the array passed to be the appropriate type ("float" or "double") to match the compute word size passed in ex_create or ex_open.

In case of an error, ex_get_time returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- no time steps have been stored in the file.

```
int ex_get_time (int exoid,
                 int time_step,
                 void *time_value)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int time_step` [in]
: The time step number. This is essentially an index (in the time dimension) into the global, nodal, and element variables arrays stored in the database. The first time step is 1.

`void* time_value` [out]
: Returned time at the specified time step.

As an example, the following coding will read the time value stored in the data file for time step n:

```
int n, error, exoid;
float time_value;

/* read time value at time step 3 */
n = 3;
error = ex_get_time (exoid, n, &time_value);
```

5.3.7 Read All Time Values

The function ex_get_all_times reads the time values for all time steps. Memory must be allocated for the time values array before this function is invoked. The storage requirements (equal to the number of time steps) can be determined by using the ex_inquire or ex_inquire_int routines.

Because time values are floating point values, the application code must declare the array passed to be the appropriate type ("float" or "double") to match the compute word size passed in ex_create or ex_open.

In case of an error, ex_get_all_times returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open

- no time steps have been stored in the file.

```
int ex_get_all_times (int exoid,
                      void *time_values)
```

`int exoid` [in]
EXODUS file ID returned from a previous call to ex_create or ex_open.

`void* time_values` [out]
Returned array of times. These are the time values at all time steps.

The following code segment will read the time values for all time steps stored in the data file:

```
#include "exodusII.h"
int error, exoid, num_time_steps;
float *time_values;

/* determine how many time steps are stored */
num_time_steps = ex_inquire_int(exoid, EX_INQ_TIME);

/* read time values at all time steps */
time_values = (float *) calloc(num_time_steps, sizeof(float));

error = ex_get_all_times(exoid, time_values);
```

5.3.8 Write Element Variable Truth Table

The function ex_put_elem_var_tab writes the EXODUS element variable truth table to the database. The element variable truth table indicates whether a particular element result is written for the elements in a particular element block. A 0 (zero) entry indicates that no results will be output for that element variable for that element block. A non-zero entry indicates that the appropriate results will be output.

Although writing the element variable truth table is optional, it is encouraged because it creates at one time all the necessary `NetCDF` variables in which to hold the EXODUS element variable values. This results in significant time savings. See Appendix A for a discussion of efficiency issues.

The function ex_put_variable_param must be called before this routine in order to define the number of element variables.

In case of an error, ex_put_elem_var_tab returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.
- data file not initialized properly with call to ex_put_init.
- the specified number of element blocks is different than the number specified in a call to ex_put_init.
- ex_put_elem_block not called previously to specify element block parameters.

- ex_put_variable_param not called previously to specify the number of element variables or was called but with a different number of element variables.
- ex_put_elem_var previously called.

```
int ex_put_elem_var_tab (int exoid,
                         int num_elem_blk,
                         int num_elem_var,
                         int **elem_var_tab)
```

`int exoid` [in]
EXODUS file ID returned from a previous call to ex_create or ex_open.

`int num_elem_blk` [in]
The number of element blocks.

`int num_elem_var` [in]
The number of element variables.

`int elem_var_tab[num_elem_blk,num_elem_var]` [in]
A 2-dimensional array (with the `num_elem_var` index cycling faster) containing the element variable truth table.

The following coding will create, populate, and write an element variable truth table to an opened EXODUS file (NOTE: all element variables are valid for all element blocks in this example.):

```
int *truth_tab, num_elem_blk, num_ele_vars, error, exoid;

/* write element variable truth table */
truth_tab = (int *)calloc((num_elem_blk*num_ele_vars), sizeof(int));

for (i=0, k=0; i < num_elem_blk; i++) {
   for (j=0; j < num_ele_vars; j++) {
      truth_tab[k++] = 1;
   }
}
error = ex_put_elem_var_tab(exoid, num_elem_blk, num_ele_vars,
                            truth_tab);
```

5.3.9 Read Element Variable Truth Table

The function ex_get_elem_var_tab reads the EXODUS element variable truth table from the database. For a description of the truth table, see the usage of the function ex_put_elem_var_tab. Memory must be allocated for the truth table(`num_elem_blk` × `num_elem_var` in length) before this function is invoked. If the truth table is not stored in the file, it will be created based on information in the file and then returned.

In case of an error, ex_get_elem_var_tab returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open

- data file not initialized properly with call to ex_put_init .
- the specified number of element blocks is different than the number specified in a call to ex_put_init .
- there are no element variables stored in the file or the specified number of element variables doesn't match the number specified in a call to ex_put_variable_param.

```
int ex_get_elem_var_tab (int exoid,
                         int num_elem_blk,
                         int num_elem_var,
                         int *elem_var_tab)
```

`int exoid` [in]
: exo file ID returned from a previous call to ex_create or ex_open.

`int num_elem_blk` [in]
: The number of element blocks.

`int num_elem_var` [in]
: The number of element variables.

`int elem_var_tab[num_elem_blk,num_elem_var]` [out]
: Returned 2-dimensional array (with the `num_elem_var` index cycling faster) containing the element variable truth table.

As an example, the following coding will read the element variable truth table from an opened EXODUS file:

```
int *truth_tab, num_elem_blk, num_ele_vars, error, exoid;

truth_tab = (int *) calloc ((num_elem_blk*num_ele_vars),
                            sizeof(int));

error = ex_get_elem_var_tab (exoid, num_elem_blk, num_ele_vars,
                             truth_tab);
```

5.3.10 Write Element Variable Values at a Time Step

The function ex_put_elem_var writes the values of a single element variable for one element block at one time step. It is recommended, but not required, to write the element variable truth table (with ex_put_elem_var_tab before this function is invoked for better efficiency. See Appendix A for a discussion of efficiency issues.

Because element variables are floating point values, the application code must declare the array passed to be the appropriate type ("float" or "double") to match the compute word size passed in ex_create or ex_open.

In case of an error, ex_put_elem_var returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.
- data file not initialized properly with call to ex_put_init .
- invalid element block ID.
- ex_put_elem_block not called previously to specify parameters for this element block.
- ex_put_variable_param not called previously specifying the number of element variables.
- an element variable truth table was stored in the file but contains a zero (indicating no valid element variable) for the specified element block and element variable.

```
int ex_put_elem_var (int exoid,
                     int time_step,
                     int elem_var_index,
                     int elem_blk_id,
                     int num_elem_this_blk,
                     void *elem_var_vals)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int time_step` [in]
: The time step number, as described under ex_put_time. This is essentially a counter that is incremented only when results variables are output. The first time step is 1.

`int elem_var_index` [in]
: The index of the element variable. The first variable has an index of 1.

`int elem_blk_id` [in]
: The element block ID.

`int num_elem_this_blk` [in]
: The number of elements in the given element block.

`void* elem_var_vals` [in]
: Array of `num_elem_this_blk` values of the `elem_var_index`$^{\mathrm{th}}$ element variable for the element block with ID of `elem_blk_id` at the `time_step`$^{\mathrm{th}}$ time step.

The following coding will write out all of the element variables for a single time step n to an open EXODUS file:

```
int num_ele_vars, num_elem_blk, *num_elem_in_block,error,
    exoid, n, *ebids;

/* write element variables */
for (k=1; k <= num_ele_vars; k++) {
   for (j=0; j < num_elem_blk; j++) {
```

```
      float *elem_var_vals = (float *)
         calloc(num_elem_in_block[j], sizeof(float));

         for (m=0; m < num_elem_in_block[j]; m++) {
            /* simulation code fills this in */
            elem_var_vals[m] = 10.0;
         }

      error = ex_put_elem_var (exoid, n, k, ebids[j],
                               num_elem_in_block[j], elem_var_vals);
      free (elem_var_vals);
   }
}
```

5.3.11 Read Element Variable Values at a Time Step

The function ex_get_elem_var reads the values of a single element variable for one element block at one time step. Memory must be allocated for the element variable values array before this function is invoked.

Because element variables are floating point values, the application code must declare the array passed to be the appropriate type (“float” or “double”) to match the compute word size passed in ex_create or ex_open.

In case of an error, ex_get_elem_var returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- variable does not exist for the desired element block.
- invalid element block.

```
int ex_get_elem_var (int exoid,
                     int time_step,
                     int elem_var_index,
                     int elem_blk_id,
                     int num_elem_this_blk,
                     void *elem_var_vals)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int time_step` [in]
: The time step number, as described under ex_put_time, at which the element variable values are desired. This is essentially an index (in the time dimension) into the element variable values array stored in the database. The first time step is 1.

`int elem_var_index` [in]
: The index of the desired element variable. The first variable has an index of 1.

`int elem_blk_id` [in]

The desired element block ID.

`int num_elem_this_blk` [in]

The number of elements in this element block.

void* elem˙var˙vals [out]

Returned array of `num_elem_this_blk` values of the `elem_var_index`th element variable for the element block with ID of `elem_blk_id` at the `time_step`th time step.

As an example, the following code segment will read the `var_index`th element variable at one time step stored in an EXODUS file:

```
int num_elem_blk, error, exoid, *num_elem_in_block,  step, var_ind;

int *ids = (int *) calloc(num_elem_blk, sizeof(int));
error = ex_get_elem_blk_ids (exoid, ids);

step = 1; /* read at the first time step */
for (i=0; i < num_elem_blk; i++) {
   float *var_vals = (float *) calloc (num_elem_in_block[i], sizeof(float));
   error = ex_get_elem_var (exoid, step, var_ind, ids[i],
                            num_elem_in_block[i], var_vals);
   free (var_values);
}
```

5.3.12 Read Element Variable Values through Time

The function ex_get_elem_var_time reads the values of an element variable for a single element through a specified number of time steps. Memory must be allocated for the element variable values array before this function is invoked.

Because element variables are floating point values, the application code must declare the array passed to be the appropriate type (“float” or “double”) to match the compute word size passed in ex_create or ex_open.

In case of an error, ex_get_elem_var_time returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file not initialized properly with call to ex_put_init .
- ex_put_elem_block not called previously to specify parameters for all element blocks.
- variable does not exist for the desired element or results haven’t been written.

```
int ex_get_elem_var_time (int exoid,
                          int elem_var_index,
                          int elem_number,
                          int beg_time_step,
                          int end_time_step,
                          void *elem_var_vals)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int elem_var_index` [in]
: The index of the desired element variable. The first variable has an index of 1.

`int elem_number` [in]
: The internal ID (see Section 4.6) of the desired element. The first element is 1.

`int beg_time_step` [in]
: The beginning time step for which an element variable value is desired. This is not a time value but rather a time step number, as described under ex_put_time. The first time step is 1.

`int end_time_step` [in]
: The last time step for which an element variable value is desired. If negative, the last time step in the database will be used. The first time step is 1.

`void* elem_var_vals` [out]
: Returned array of(`end_time_step` - `beg_time_step` + 1) values of the `elem_number`th element for the `elem_var_index`th element variable.

For example, the following coding will read the values of the `var_index`th element variable for element number 2 from the first time step to the last time step:

```
/* determine how many time steps are stored */
int num_time_steps = ex_inquire_int(exoid, EX_INQ_TIME);

/* read an element variable through time */
float *var_values = (float *) calloc (num_time_steps, sizeof(float));
int var_index = 2;

int elem_num = 2;

int beg_time =  1;
int end_time = -1;

int error = ex_get_elem_var_time (exoid, var_index, elem_num,
                                  beg_time, end_time, var_values);
```

5.3.13 Write Global Variables Values at a Time Step

The function ex_put_glob_vars writes the values of all the global variables for a single time step. The function ex_put_variable_param must be invoked before this call is made.

Because global variables are floating point values, the application code must declare the array passed to be the appropriate type ("float" or "double") to match the compute word size passed in ex_create or ex_open.

In case of an error, ex_put_glob_vars returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open

- data file opened for read only.
- ex_put_variable_param not called previously specifying the number of global variables.

```
int ex_put_glob_vars (int exoid,
                      int time_step,
                      int num_glob_vars,
                      void *glob_var_vals)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int time_step` [in]
: The time step number, as described under ex_put_time. This is essentially a counter that is incremented when results variables are output. The first time step is 1.

`int num_glob_vars` [in]
: The number of global variables to be written to the database.

`void* glob_var_vals` [in]
: Array of **num_glob_vars** global variable values for the **time_step**th time step.

As an example, the following coding will write the values of all the global variables at one time step to an open EXODUS II file:

```
int num_glo_vars, error, exoid, time_step;

float *glob_var_vals

/* write global variables */
for (j=0; j < num_glo_vars; j++) {
   /* application code fills this array */
   glob_var_vals[j] = 10.0;
}
error = ex_put_glob_vars (exoid, time_step, num_glo_vars,
                          glob_var_vals);
```

5.3.14 Read Global Variables Values at a Time Step

The function ex_get_glob_vars reads the values of all the global variables for a single time step. Memory must be allocated for the global variables values array before this function is invoked.

Because global variables are floating point values, the application code must declare the array passed to be the appropriate type ("float" or "double") to match the compute word size passed in ex_create or ex_open.

In case of an error, ex_get_glob_vars returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open

- no global variables stored in the file.
- a warning value is returned if no global variables are stored in the file.

```
int ex_get_glob_vars (int exoid,
                      int time_step,
                      int num_glob_vars,
                      void *glob_var_vals)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int time_step` [in]
: The time step, as described under ex_put_time, at which the global variable values are desired. This is essentially an index (in the time dimension) into the global variable values array stored in the database. The first time step is 1.

`int num_glob_vars` [in]
: The number of global variables stored in the database.

`void* glob_var_vals` [out]
: Returned array of `num_glob_vars` global variable values for the `time_step`th time step.

The following is an example code segment that reads all the global variables at one time step:

```
int num_glo_vars, time_step;

int error = ex_get_variable_param (idexo, EX_GLOBAL, &num_glo_vars);
float *var_values = (float *) calloc (num_glo_vars, sizeof(float));
error = ex_get_glob_vars (idexo, time_step, num_glo_vars,
                          var_values);
```

5.3.15 Read Global Variable Values through Time

The function ex_get_glob_var_time reads the values of a single global variable through a specified number of time steps. Memory must be allocated for the global variable values array before this function is invoked.

Because global variables are floating point values, the application code must declare the array passed to be the appropriate type ("float" or "double") to match the compute word size passed in ex_create or ex_open.

In case of an error, ex_get_glob_var_time returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- specified global variable does not exist.
- a warning value is returned if no global variables are stored in the file.

```
int ex_get_glob_var_time (int exoid,
                          int glob_var_index,
                          int beg_time_step,
                          int end_time_step,
                          void *glob_var_vals)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int glob_var_index` [in]
: The index of the desired global variable. The first variable has an index of 1.

`int beg_time_step` [in]
: The beginning time step for which a global variable value is desired. This is not a time value but rather a time step number, as described under ex_put_time. The first time step is 1.

`int end_time_step` [in]
: The last time step for which a global variable value is desired. If negative, the last time step in the database will be used. The first time step is 1.

`void* glob_var_vals` [out]
: Returned array of (end˙time˙step - beg˙time˙step + 1) values for the `glob_var_index`th global variable.

The following is an example of using this function:

```
#include "exodusII.h"
int error, exoid, num_time_steps, var_index;
int beg_time, end_time;

float *var_values;

/* determine how many time steps are stored */
num_time_steps = ex_inquire_int(exoid, EX_INQ_TIME);

/* read the first global variable for all time steps */
var_index = 1;
beg_time = 1;
end_time = -1;

var_values = (float *) calloc (num_time_steps, sizeof(float));

error = ex_get_glob_var_time(exoid, var_index, beg_time,
                             end_time, var_values);
```

5.3.16 Write Nodal Variable Values at a Time Step

The function ex_put_nodal_var writes the values of a single nodal variable for a single time step. The function ex_put_variable_param must be invoked before this call is made.

Because nodal variables are floating point values, the application code must declare the array passed to be the appropriate type ("float" or "double") to match the compute word size passed in ex_create or ex_open.

In case of an error, ex_put_nodal_var returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- data file opened for read only.
- data file not initialized properly with call to ex_put_init.
- ex_put_variable_param not called previously specifying the number of nodal variables.

```
int ex_put_nodal_var (int exoid,
                      int time_step,
                      int nodal_var_index,
                      int num_nodes,
                      void *nodal_var_vals)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int time_step` [in]
: The time step number, as described under ex_put_time. This is essentially a counter that is incremented when results variables are output. The first time step is 1.

`int nodal_var_index` [in]
: The index of the nodal variable. The first variable has an index of 1.

`int num_nodes` [in]
: The number of nodal points.

`void* nodal_var_vals` [in]
: Array of `num_nodes` values of the `nodal_var_index`th nodal variable for the `time_step`th time step.

As an example, the following code segment writes all the nodal variables for a single time step:

```
int num_nod_vars, num_nodes, error, exoid, time_step;

/* write nodal variables */
float *nodal_var_vals = (float *) calloc(num_nodes, sizeof(float));
for (k=1; k <= num_nod_vars; k++) {
   for (j=0; j < num_nodes; j++) {
      /* application code fills in this array */
      nodal_var_vals[j] = 10.0;
   }
   error = ex_put_nodal_var(exoid, time_step, k, num_nodes,
                            nodal_var_vals);
}
```

5.3.17 Read Nodal Variable Values at a Time Step

The function ex_get_nodal_var reads the values of a single nodal variable for a single time step. Memory must be allocated for the nodal variable values array before this function is invoked.

Because nodal variables are floating point values, the application code must declare the array passed to be the appropriate type ("float" or "double") to match the compute word size passed in ex_create or ex_open.

In case of an error, ex_get_nodal_var returns a negative number; a warning will return a positive number. Possible causes of errors include:

- data file not properly opened with call to ex_create or ex_open
- specified nodal variable does not exist.
- a warning value is returned if no nodal variables are stored in the file.

```
int ex_get_nodal_var (int exoid,
                      int time_step,
                      int nodal_var_index,
                      int num_nodes,
                      void *nodal_var_vals)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int time_step` [in]
: The time step, as described under ex_put_time, at which the nodal variable values are desired. This is essentially an index (in the time dimension) into the nodal variable values array stored in the database. The first time step is 1.

`int nodal_var_index` [in]
: The index of the desired nodal variable. The first variable has an index of 1.

`int num_nodes` [in]
: The number of nodal points.

`void* nodal_var_vals` [out]
: Returned array of `num_nodes` values of the `nodal_var_index`th nodal variable for the `time_step`th time step.

For example, the following demonstrates how this function would be used:

```
/* read the second nodal variable at the first time step */
int time_step = 1;
int var_index = 2;

float *var_values = (float *) calloc (num_nodes, sizeof(float));
error = ex_get_nodal_var(exoid, time_step, var_index, num_nodes,
                         var_values);
```

5.3.18 Read Nodal Variable Values through Time

The function ex_get_nodal_var_time reads the values of a nodal variable for a single node through a specified number of time steps. Memory must be allocated for the nodal variable values array before this function is invoked.

Because nodal variables are floating point values, the application code must declare the array passed to be the appropriate type ("float" or "double") to match the compute word size passed in ex_create or ex_open.

In case of an error, ex_get_nodal_var_time returns a negative number; a warning will return a positive number. Possible causes of errors include:

- specified nodal variable does not exist.
- a warning value is returned if no nodal variables are stored in the file.

```
int ex_get_nodal_var_time (int exoid,
                           int nodal_var_index,
                           int node_number,
                           int beg_time_step,
                           int end_time_step,
                           void *nodal_var_vals)
```

`int exoid` [in]
: EXODUS file ID returned from a previous call to ex_create or ex_open.

`int nodal_var_index` [in]
: The index of the desired nodal variable. The first variable has an index of 1.

`int node_number` [in]
: The internal ID (see Section 4.5) of the desired node. The first node is 1.

`int beg_time_step` [in]
: The beginning time step for which a nodal variable value is desired. This is not a time value but rather a time step number, as described under ex_put_time. The first time step is 1.

`int end_time_step` [in]
: The last time step for which a nodal variable value is desired. If negative, the last time step in the database will be used. The first time step is 1.

`void* nodal_var_vals` [out]
: Returned array of(`end_time_step` - `beg_time_step` +1) values of the `node_number`$^{\text{th}}$ node for the `nodal_var_index`$^{\text{th}}$ nodal variable.

For example, the following code segment will read the values of the first nodal variable for node number one for all time steps stored in the data file:

```
#include "exodusII.h"
int node_num, beg_time, end_time, error, exoid;
```

```

/* determine how many time steps are stored */
int num_time_steps = ex_inquire_int(exoid, EX_INQ_TIME);

/* read a nodal variable through time */
float *var_values = (float *) calloc (num_time_steps, sizeof(float));

int var_index = 1; node_num = 1; beg_time = 1; end_time = -1;
error = ex_get_nodal_var_time(exoid, var_index, node_num, beg_time,
                              end_time, var_values);
```

Chapter 6

References

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[2] G. D. Sjaardema, "Overview of the Sandia National Laboratories Engineering Analysis Code Access System," Technical Report SAND92-2292, Sandia National Laboratories, Albuquerque, New Mexico, January 1993.

[3] R. K. Rew, G. P. Davis, and S. Emmerson, "NetCDF User's Guide: An Interface for Data Access," Version 2.3, University Corporation for Atmospheric Research, Boulder, Colorado, April 1993.

[4] Sun Microsystems, "External Data Representation Standard: Protocol Specification," RFC 1014; Information Sciences Institute, May 1988.

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*

Appendix A

Implementation of EXODUS with NetCDF

A.1 Description

The `NetCDF` software is an I/O library, callable from C or Fortran, which stores and retrieves scientific data structures in self-describing, machine-independent files. *Self-describing means that a file includes information defining the data it contains.* Machine-independent means that a file is represented in a form that can be accessed by computers with different ways of storing integers, characters, and floating-point numbers. It is available via the web from `http://www.unidata.ucar.edu`. The current version is 3.6.2 although version 4.0 is expected to be released soon.

For the EXODUS implementation, the standard `NetCDF` distribution is used except that the following defined constants in the include file ***netcdf.h*** are modified to the values shown:

```
#define NC_MAX_DIMS 65536
#define NC_MAX_VARS 524288
#define NC_MAX_VAR_DIMS 8
```

A.2 Efficiency Issues

There are some efficiency concerns with using `NetCDF` as the low level data handler. The main one is that whenever a new object is introduced, the file is put into *define mode, the new object is defined, and then the file is taken out of* define mode. A result of going in and out of *define mode is that all of the data that was output previous to the introduction of the new object is copied to a new file. Obviously, this copying of data to a new file is very inefficient. We have attempted to minimize the number of times the data file is put into* define mode by accumulating objects within a single EXODUS API function. Thus using optional features such as the element variable truth table, concatenated node and side sets, and writing all property array names with ex_put_prop_names will increase efficiency significantly.

Appendix B

Deprecated Functions

ex_get_concat_node_sets

Use ex_get_concat_sets (exoid, EX_NODE_SET, set_specs) [See Section ??]

ex_get_concat_side_sets

Use ex_get_concat_sets (exoid, EX_SIDE_SET, set_specs) [See Section ??]

ex_get_elem_attr

Use ex_get_attr (exoid, EX_ELEM_BLOCK, elem_blk_id, attrib) [See Section ??]

ex_get_elem_attr_names

Use ex_get_attr_names(exoid, EX_ELEM_BLOCK, elem_blk_id, names) [See Section ??]

ex_get_elem_blk_ids

Use ex_get_ids (exoid, EX_ELEM_BLOCK, ids) [See Section ??]

ex_get_elem_block

Use
ex_get_block(exoid, EX_ELEM_BLOCK, elem_blk_id, elem_type, num_elem_this_blk, num_nodes_per_elem, num_attr
[See Section ??]

ex_get_elem_conn

Use ex_get_conn(exoid, EX_ELEM_BLOCK, elem_blk_id, connect, 0, 0) [See Section ??]

ex_get_elem_map

Use ex_get_num_map(exoid, EX_ELEM_MAP, map_id, elem_map) [See Section ??]

ex_get_elem_var

Use
ex_get_var (exoid, time_step, EX_ELEM_BLOCK, elem_var_index, elem_blk_id, num_elem_this_blk, elem_var_vals)
[See Section ??]

ex_get_elem_var_tab

Use
ex_get_truth_table (exoid, EX_ELEM_BLOCK, num_elem_blk, num_elem_var, elem_var_tab)

[See Section ??]

ex_get_elem_var_time

Use
ex_get_var_time(exoid, EX_ELEM_BLOCK, elem_var_index, elem_number, beg_time_step, end_time_step, elem_var_v
[See Section ??]

ex_get_elem_varid

Use ex_get_varid (exoid, EX_ELEM_BLOCK, varid) [See Section ??]

ex_get_map

Use ex_get_num_map [See Section ??]

ex_get_node_map

Use ex_get_num_map(exoid, EX_NODE_MAP, map_id, node_map) [See Section ??]

ex_get_node_set

Use ex_get_set (exoid, EX_NODE_SET, node_set_id, node_set_node_list, NULL) [See Section ??]

ex_get_node_set_dist_fact

Use ex_get_set_dist_fact (exoid, EX_NODE_SET, node_set_id, node_set_dist_fact) [See Section ??]

ex_get_node_set_ids

Use ex_get_ids (exoid, EX_NODE_SET, ids) [See Section ??]

ex_get_node_set_param

Use ex_get_set_param(exoid, EX_NODE_SET, node_set_id, num_nodes_in_set, num_df_in_set) [See Section ??]

ex_get_nset_var

Use
ex_get_var (exoid, time_step, EX_NODE_SET, nset_var_index, nset_id, num_node_this_nset, nset_var_vals)
[See Section ??]

ex_get_nset_var_tab

Use ex_get_truth_table (exoid, EX_NODE_SET, num_nodesets, num_nset_var, nset_var_tab) [See Section ??]

ex_get_nset_varid

Use ex_get_varid (exoid, EX_NODE_SET, varid) [See Section ??]

ex_get_one_elem_attr

Use ex_get_one_attr (exoid, EX_ELEM_BLOCK, elem_blk_id, attrib_index, attrib) [See Section ??]

ex_get_side_set

Use ex_get_set (exoid, EX_SIDE_SET, side_set_id, side_set_elem_list , side_set_side_list) [See

Section ??]

ex_get_side_set_dist_fact

Use ex_get_set_dist_fact (exoid, EX_SIDE_SET, side_set_id, side_set_dist_fact) [See Section ??]

ex_get_side_set_ids

Use ex_get_ids (exoid, EX_SIDE_SET, ids) [See Section ??]

ex_get_side_set_param

Use
ex_get_set_param(exoid, EX_SIDE_SET, side_set_id, num_side_in_set, num_dist_fact_in_set)
[See Section ??]

ex_get_sset_var

Use
ex_get_var (exoid, time_step, EX_SIDE_SET, sset_var_index, sset_id, num_side_this_sset , sset_var_vals)
[See Section ??]

ex_get_sset_var_tab

Use ex_get_truth_table (exoid, EX_SIDE_SET, num_sidesets, num_sset_var, sset_var_tab) [See Section ??]

ex_get_sset_varid

Use ex_get_varid (exoid, EX_SIDE_SET, varid) [See Section ??]

ex_get_var_name

use ex_get_variable_name(exoid, obj_type, var_num, *var_name) [See Section ??]

ex_get_var_names

Use ex_get_variable_names(exoid, obj_type, num_vars, var_names) [See Section ??]

ex_get_var_param

Use ex_get_variable_param(exoid, obj_type, *num_vars) [See Section ??]

ex_get_var_tab

Use ex_get_truth_table (exoid, obj_type, num_blk, num_var, var_tab) [See Section ??]

ex_put_concat_node_sets

Use ex_put_concat_sets (exoid, EX_NODE_SET, &set_specs) [See Section ??]

ex_put_concat_side_sets

Use ex_put_concat_sets (exoid, EX_SIDE_SET, set_specs) [See Section ??]

ex_put_concat_var_param

Use ex_put_all_var_param(exoid, num_g, num_n, num_e, elem_var_tab, 0, 0, 0, 0) [See Section ??]

ex_put_elem_attr

Use ex_put_attr(exoid, EX_ELEM_BLOCK, elem_blk_id, attrib) [See Section ??]

ex_put_elem_attr_names

Use ex_put_attr_names(exoid, EX_ELEM_BLOCK, elem_blk_id, names) [See Section ??]

ex_put_elem_block

Use
ex_put_block(exoid, EX_ELEM_BLOCK, elem_blk_id, elem_type, num_elem_this_blk, num_nodes_per_elem, 0, 0, nun
[See Section ??]

ex_put_elem_conn

Use ex_put_conn(exoid, EX_ELEM_BLOCK, elem_blk_id, connect, 0, 0) [See Section ??]

ex_put_elem_map

Use ex_put_num_map(exoid, EX_ELEM_MAP, map_id, elem_map) [See Section ??]

ex_put_elem_num_map

Use ex_put_id_map(exoid, EX_ELEM_MAP, elem_map) [See Section ??]

ex_put_elem_var

Use
ex_put_var(exoid, time_step, EX_ELEM_BLOCK, elem_var_index, elem_blk_id, num_elem_this_blk, elem_var_vals)
[See Section ??]

ex_put_elem_var_tab

Use
ex_put_truth_table(exoid, EX_ELEM_BLOCK, num_elem_blk, num_elem_var, elem_var_tab)
[See Section ??]

ex_put_glob_vars

Use ex_put_var(exoid, time_step, EX_GLOBAL, 1, 0, num_glob_vars, glob_var_vals) [See Section ??]

ex_put_map

Use ex_put_num_map [See Section ??]

ex_put_node_map

Use ex_put_num_map(exoid, EX_NODE_MAP, map_id, node_map) [See Section ??]

ex_put_node_num_map

Use ex_put_id_map(exoid, EX_NODE_MAP, node_map) [See Section ??]

ex_put_node_set

Use ex_put_set(exoid, EX_NODE_SET, node_set_id, node_set_node_list, NULL) [See Section ??]

ex_put_node_set_dist_fact

Use ex_put_set_dist_fact (exoid, EX_NODE_SET, node_set_id, node_set_dist_fact) [See

Section ??]

ex_put_node_set_param

Use ex_put_set_param(exoid, EX_NODE_SET, node_set_id, num_nodes_in_set, num_dist_in_set) [See Section ??]

ex_put_nset_var

Use ex_put_var(exoid, time_step, EX_NODE_SET, nset_var_index, nset_id, num_nodes_this_nset, nset_var_vals) [See Section ??]

ex_put_nset_var_tab

Use ex_put_truth_table(exoid, EX_NODE_SET, num_nset, num_nset_var, nset_var_tab) [See Section ??]

ex_put_one_elem_attr

Use ex_put_one_attr(exoid, EX_ELEM_BLOCK, elem_blk_id, attrib_index, attrib) [See Section ??]

ex_put_side_set

Use ex_put_set(exoid, EX_SIDE_SET, side_set_id, side_set_elem_list , side_set_side_list) [See Section ??]

ex_put_side_set_dist_fact

Use ex_put_set_dist_fact (exoid, EX_SIDE_SET, side_set_id, side_set_dist_fact) [See Section ??]

ex_put_side_set_param

Use ex_put_set_param(exoid, EX_SIDE_SET, side_set_id, num_side_in_set, num_dist_fact_in_set) [See Section ??]

ex_put_sset_var

Use ex_put_var(exoid, time_step, EX_SIDE_SET, sset_var_index, sset_id, num_faces_this_sset , sset_var_vals) [See Section ??]

ex_put_sset_var_tab

Use ex_put_truth_table(exoid, EX_SIDE_SET, num_sset, num_sset_var, sset_var_tab) [See Section ??]

ex_put_var_name

use ex_put_variable_name(exoid, obj_type, var_num, *var_name) [See Section ??]

ex_put_var_names

Use ex_put_variable_names(exoid, obj_type, num_vars, var_names) [See Section ??]

ex_put_var_param

Use ex_put_variable_param(exoid, obj_type, num_vars) [See Section ??]

ex_put_var_tab

Use ex_put_truth_table(exoid, obj_type, num_blk, num_var, var_tab) [See Section **??**]

Appendix C

Sample Code

This appendix contains examples of C programs that use the EXODUS API.

C.1 Write Example Code

The following is a C program that creates and populates an EXODUS file:

```c
/*
 * Copyright(C) 1999-2023 National Technology & Engineering Solutions
 * of Sandia, LLC (NTESS).  Under the terms of Contract DE-NA0003525 with
 * NTESS, the U.S. Government retains certain rights in this software.
 *
 * See packages/seacas/LICENSE for details
 */
#include <stdio.h>
#include <stdlib.h>
#include <string.h>

#include "exodusII.h"
#include "exodusII_int.h"

/* Somewhat cleaner way to check for and report exodus errors... */
#define STRINGIFY(x) #x
#define TOSTRING(x)  STRINGIFY(x)

#define EXCHECK(funcall)                                                  \
  do {                                                                    \
    int f_error = (funcall);                                              \
    printf("after %s, error = %d\n", TOSTRING(funcall), f_error);         \
    if (f_error != EX_NOERR && f_error != EX_WARN) {                      \
      fprintf(stderr, "Error calling %s\n", TOSTRING(funcall));           \
      ex_close(exoid);                                                    \
      exit(-1);                                                           \
    }                                                                     \
  } while (0)
/* End of check */

```

```c
int main(int argc, char **argv)
{
  ex_opts(EX_VERBOSE);

  /* Specify compute and i/o word size */
  int CPU_word_size = 0; /* sizeof(float) */
  int IO_word_size  = 4; /* (4 bytes) */

  /* create EXODUS II file */
  int exoid = ex_create("test.exo",      /* filename path */
                        EX_CLOBBER,      /* create mode */
                        &CPU_word_size, /* CPU float word size in bytes */
                        &IO_word_size); /* I/O float word size in bytes */
  printf("after␣ex_create␣for␣test.exo,␣exoid␣=␣%d\n", exoid);
  printf("␣cpu␣word␣size:␣%d␣io␣word␣size:␣%d\n", CPU_word_size, IO_word_size);

  /* initialize file with parameters */
  int num_dim       = 3;
  int num_nodes     = 33;
  int num_elem      = 7;
  int num_elem_blk  = 7;
  int num_node_sets = 2;
  int num_side_sets = 5;

  char *title = "This␣is␣a␣test";
  EXCHECK(ex_put_init(exoid, title, num_dim, num_nodes, num_elem,
                      num_elem_blk, num_node_sets, num_side_sets));

  /* clang-format off */
  /* write nodal coordinates values and names to database */

  /* Quad #1 */
  float x[100], y[100], z[100];
  x[0] = 0.0;  y[0] = 0.0;  z[0] = 0.0;
  x[1] = 1.0;  y[1] = 0.0;  z[1] = 0.0;
  x[2] = 1.0;  y[2] = 1.0;  z[2] = 0.0;
  x[3] = 0.0;  y[3] = 1.0;  z[3] = 0.0;

  /* Quad #2 */
  x[4] = 1.0;  y[4] = 0.0;  z[4] = 0.0;
  x[5] = 2.0;  y[5] = 0.0;  z[5] = 0.0;
  x[6] = 2.0;  y[6] = 1.0;  z[6] = 0.0;
  x[7] = 1.0;  y[7] = 1.0;  z[7] = 0.0;

  /* Hex #1 */
  x[8]  = 0.0;   y[8]  = 0.0;  z[8]  = 0.0;
  x[9]  = 10.0;  y[9]  = 0.0;  z[9]  = 0.0;
  x[10] = 10.0;  y[10] = 0.0;  z[10] = -10.0;
  x[11] = 1.0;   y[11] = 0.0;  z[11] = -10.0;
  x[12] = 1.0;   y[12] = 10.0; z[12] = 0.0;
  x[13] = 10.0;  y[13] = 10.0; z[13] = 0.0;
  x[14] = 10.0;  y[14] = 10.0; z[14] = -10.0;
  x[15] = 1.0;   y[15] = 10.0; z[15] = -10.0;

  /* Tetra #1 */
```

```
x[16] = 0.0;  y[16] = 0.0;  z[16] = 0.0;
x[17] = 1.0;  y[17] = 0.0;  z[17] = 5.0;
x[18] = 10.0; y[18] = 0.0;  z[18] = 2.0;
x[19] = 7.0;  y[19] = 5.0;  z[19] = 3.0;

/* Wedge #1 */
x[20] = 3.0;  y[20] = 0.0;  z[20] = 6.0;
x[21] = 6.0;  y[21] = 0.0;  z[21] = 0.0;
x[22] = 0.0;  y[22] = 0.0;  z[22] = 0.0;
x[23] = 3.0;  y[23] = 2.0;  z[23] = 6.0;
x[24] = 6.0;  y[24] = 2.0;  z[24] = 2.0;
x[25] = 0.0;  y[25] = 2.0;  z[25] = 0.0;

/* Tetra #2 */
x[26] = 2.7;  y[26] = 1.7;  z[26] = 2.7;
x[27] = 6.0;  y[27] = 1.7;  z[27] = 3.3;
x[28] = 5.7;  y[28] = 1.7;  z[28] = 1.7;
x[29] = 3.7;  y[29] = 0.0;  z[29] = 2.3;

/* 3d Tri */
x[30] = 0.0;  y[30] = 0.0;  z[30] = 0.0;
x[31] = 10.0; y[31] = 0.0;  z[31] = 0.0;
x[32] = 10.0; y[32] = 10.0; z[32] = 10.0;
/* clang-format on */

EXCHECK(ex_put_coord(exoid, x, y, z));

char *coord_names[] = {"xcoor", "ycoor", "zcoor"};
EXCHECK(ex_put_coord_names(exoid, coord_names));

/* Add nodal attributes */
EXCHECK(ex_put_attr_param(exoid, EX_NODAL, 0, 2));
EXCHECK(ex_put_one_attr(exoid, EX_NODAL, 0, 1, x));
EXCHECK(ex_put_one_attr(exoid, EX_NODAL, 0, 2, y));

{
  char *attrib_names[] = {"Node_attr_1", "Node_attr_2"};
  EXCHECK(ex_put_attr_names(exoid, EX_NODAL, 0, attrib_names));
}

/* write element id map */
int *elem_map = (int *)calloc(num_elem, sizeof(int));
for (int i = 1; i <= num_elem; i++) {
  elem_map[i - 1] = i * 10;
}

EXCHECK(ex_put_id_map(exoid, EX_ELEM_MAP, elem_map));

free(elem_map);

/* write element block parameters */
struct ex_block blocks[10];
for (int i = 0; i < 10; i++) {
  blocks[i].type                = EX_ELEM_BLOCK;
  blocks[i].id                  = 0;
```

```
    blocks[i].num_entry           = 0;
    blocks[i].num_nodes_per_entry = 0;
    blocks[i].num_edges_per_entry = 0;
    blocks[i].num_faces_per_entry = 0;
    blocks[i].num_attribute       = 0;
  }

  char *block_names[10];
  block_names[0] = "block_1";
  block_names[1] = "block_2";
  block_names[2] = "block_3";
  block_names[3] = "block_4";
  block_names[4] = "block_5";
  block_names[5] = "block_6";
  block_names[6] = "block_7";

  ex_copy_string(blocks[0].topology, "quad", MAX_STR_LENGTH + 1);
  ex_copy_string(blocks[1].topology, "quad", MAX_STR_LENGTH + 1);
  ex_copy_string(blocks[2].topology, "hex", MAX_STR_LENGTH + 1);
  ex_copy_string(blocks[3].topology, "tetra", MAX_STR_LENGTH + 1);
  ex_copy_string(blocks[4].topology, "wedge", MAX_STR_LENGTH + 1);
  ex_copy_string(blocks[5].topology, "tetra", MAX_STR_LENGTH + 1);
  ex_copy_string(blocks[6].topology, "tri", MAX_STR_LENGTH + 1);

  blocks[0].num_entry = 1;
  blocks[1].num_entry = 1;
  blocks[2].num_entry = 1;
  blocks[3].num_entry = 1;
  blocks[4].num_entry = 1;
  blocks[5].num_entry = 1;
  blocks[6].num_entry = 1;

  blocks[0].num_attribute = 1;
  blocks[1].num_attribute = 1;
  blocks[2].num_attribute = 1;
  blocks[3].num_attribute = 1;
  blocks[4].num_attribute = 1;
  blocks[5].num_attribute = 1;
  blocks[6].num_attribute = 1;

  blocks[0].num_nodes_per_entry = 4; /* elements in block #1 are 4-node quads */
  blocks[1].num_nodes_per_entry = 4; /* elements in block #2 are 4-node quads */
  blocks[2].num_nodes_per_entry = 8; /* elements in block #3 are 8-node hexes */
  blocks[3].num_nodes_per_entry = 4; /* elements in block #4 are 4-node tetras */
  blocks[4].num_nodes_per_entry = 6; /* elements in block #5 are 6-node wedges */
  blocks[5].num_nodes_per_entry = 8; /* elements in block #6 are 8-node tetras */
  blocks[6].num_nodes_per_entry = 3; /* elements in block #7 are 3-node tris */

  blocks[0].id = 10;
  blocks[1].id = 11;
  blocks[2].id = 12;
```

```
  blocks[3].id = 13;
  blocks[4].id = 14;
  blocks[5].id = 15;
  blocks[6].id = 16;

  /* Generate an error that name is not found since blocks have not
     yet been defined
  */
  int error = ex_put_name(exoid, EX_ELEM_BLOCK, blocks[0].id, block_names[0]);
  printf("after ex_put_name, error = %d\n", error);

  EXCHECK(ex_put_block_params(exoid, num_elem_blk, blocks));

  /* Write element block names */
  for (int i = 0; i < num_elem_blk; i++) {
    EXCHECK(ex_put_name(exoid, EX_ELEM_BLOCK, blocks[i].id, block_names[i]));
  }

  /* write element block properties */
  /*                 12345678901234567890123456789012 */
  char *prop_names[2];
  prop_names[0] = "MATERIAL_PROPERTY_LONG_NAME_32CH";
  prop_names[1] = "DENSITY";

  EXCHECK(ex_put_prop_names(exoid, EX_ELEM_BLOCK, 2, prop_names));
  EXCHECK(ex_put_prop(exoid, EX_ELEM_BLOCK, blocks[0].id, prop_names[0], 10));
  EXCHECK(ex_put_prop(exoid, EX_ELEM_BLOCK, blocks[1].id, prop_names[0], 20));
  EXCHECK(ex_put_prop(exoid, EX_ELEM_BLOCK, blocks[2].id, prop_names[0], 30));
  EXCHECK(ex_put_prop(exoid, EX_ELEM_BLOCK, blocks[3].id, prop_names[0], 40));
  EXCHECK(ex_put_prop(exoid, EX_ELEM_BLOCK, blocks[4].id, prop_names[0], 50));
  EXCHECK(ex_put_prop(exoid, EX_ELEM_BLOCK, blocks[5].id, prop_names[0], 60));
  EXCHECK(ex_put_prop(exoid, EX_ELEM_BLOCK, blocks[6].id, prop_names[0], 70));

  /* write element connectivity */
  {
    int connect[] = {1, 2, 3, 4};
    EXCHECK(ex_put_conn(exoid, EX_ELEM_BLOCK, blocks[0].id, connect, NULL, NULL));
  }

  {
    int connect[] = {5, 6, 7, 8};
    EXCHECK(ex_put_conn(exoid, EX_ELEM_BLOCK, blocks[1].id, connect, NULL, NULL));
  }

  {
    int connect[] = {9, 10, 11, 12, 13, 14, 15, 16};
    EXCHECK(ex_put_conn(exoid, EX_ELEM_BLOCK, blocks[2].id, connect, NULL, NULL));
  }

  {
    int connect[] = {17, 18, 19, 20};
    EXCHECK(ex_put_conn(exoid, EX_ELEM_BLOCK, blocks[3].id, connect, NULL, NULL));
  }

  {
```

```
    int connect[] = {21, 22, 23, 24, 25, 26};
    EXCHECK(ex_put_conn(exoid, EX_ELEM_BLOCK, blocks[4].id, connect, NULL, NULL));
  }

  {
    int connect[] = {17, 18, 19, 20, 27, 28, 30, 29};
    EXCHECK(ex_put_conn(exoid, EX_ELEM_BLOCK, blocks[5].id, connect, NULL, NULL));
  }

  {
    int connect[] = {31, 32, 33};
    EXCHECK(ex_put_conn(exoid, EX_ELEM_BLOCK, blocks[6].id, connect, NULL, NULL));
  }

  /* write element block attributes */
  float attrib[1];
  attrib[0] = 3.14159;
  EXCHECK(ex_put_attr(exoid, EX_ELEM_BLOCK, blocks[0].id, attrib));
  EXCHECK(ex_put_attr(exoid, EX_ELEM_BLOCK, blocks[0].id, attrib));

  attrib[0] = 6.14159;
  EXCHECK(ex_put_attr(exoid, EX_ELEM_BLOCK, blocks[1].id, attrib));
  EXCHECK(ex_put_attr(exoid, EX_ELEM_BLOCK, blocks[2].id, attrib));
  EXCHECK(ex_put_attr(exoid, EX_ELEM_BLOCK, blocks[3].id, attrib));
  EXCHECK(ex_put_attr(exoid, EX_ELEM_BLOCK, blocks[4].id, attrib));
  EXCHECK(ex_put_attr(exoid, EX_ELEM_BLOCK, blocks[5].id, attrib));
  EXCHECK(ex_put_attr(exoid, EX_ELEM_BLOCK, blocks[6].id, attrib));

  {
    char *attrib_names[] = {"THICKNESS"};
    for (int i = 0; i < num_elem_blk; i++) {
      EXCHECK(ex_put_attr_names(exoid, EX_ELEM_BLOCK, blocks[i].id, attrib_names));
    }
  }

  /* write individual node sets */
  int num_nodes_in_nset[] = {5, 3};
  int nsids[]             = {20, 21};

  {
    EXCHECK(ex_put_set_param(exoid, EX_NODE_SET, nsids[0], 5, 5));

    int   node_list[] = {10, 11, 12, 13, 14};
    float dist_fact[] = {1.0, 2.0, 3.0, 4.0, 5.0};

    EXCHECK(ex_put_set(exoid, EX_NODE_SET, nsids[0], node_list, NULL));
    EXCHECK(ex_put_set_dist_fact(exoid, EX_NODE_SET, nsids[0], dist_fact));
  }

  {
    EXCHECK(ex_put_set_param(exoid, EX_NODE_SET, nsids[1], 3, 3));

    int   node_list[] = {20, 21, 22};
    float dist_fact[] = {1.1, 2.1, 3.1};

```

```
    EXCHECK(ex_put_set(exoid, EX_NODE_SET, nsids[1], node_list, NULL));
    EXCHECK(ex_put_set_dist_fact(exoid, EX_NODE_SET, nsids[1], dist_fact));
  }

  /* Write node set names */
  char *nset_names[] = {"nset_1", "nset_2"};
  EXCHECK(ex_put_names(exoid, EX_NODE_SET, nset_names));
  EXCHECK(ex_put_prop(exoid, EX_NODE_SET, nsids[0], "FACE", 4));
  EXCHECK(ex_put_prop(exoid, EX_NODE_SET, nsids[1], "FACE", 5));

  int prop_array[] = {1000, 2000};
  EXCHECK(ex_put_prop_array(exoid, EX_NODE_SET, "VELOCITY", prop_array));

  /* Add nodeset attributes */
  EXCHECK(ex_put_attr_param(exoid, EX_NODE_SET, nsids[0], 1));
  EXCHECK(ex_put_attr(exoid, EX_NODE_SET, nsids[0], x));

  {
    char *attrib_names[] = {"Nodeset_attribute"};
    EXCHECK(ex_put_attr_names(exoid, EX_NODE_SET, nsids[0], attrib_names));
  }

  /* write individual side sets */
  int num_face_in_sset[] = {2, 2, 7, 8, 10};
  int ssids[]            = {30, 31, 32, 33, 34};

  {
    /* side set #1  - quad */
    EXCHECK(ex_put_set_param(exoid, EX_SIDE_SET, ssids[0], 2, 4));

    int   elem_list[] = {2, 2};
    int   side_list[] = {4, 2};
    float dist_fact[] = {30.0, 30.1, 30.2, 30.3};

    EXCHECK(ex_put_set(exoid, EX_SIDE_SET, 30, elem_list, side_list));
    EXCHECK(ex_put_set_dist_fact(exoid, EX_SIDE_SET, 30, dist_fact));
  }

  {
    /* side set #2  - quad, spanning 2 elements  */
    EXCHECK(ex_put_set_param(exoid, EX_SIDE_SET, 31, 2, 4));

    int   elem_list[] = {1, 2};
    int   side_list[] = {2, 3};
    float dist_fact[] = {31.0, 31.1, 31.2, 31.3};

    EXCHECK(ex_put_set(exoid, EX_SIDE_SET, 31, elem_list, side_list));
    EXCHECK(ex_put_set_dist_fact(exoid, EX_SIDE_SET, 31, dist_fact));
  }

  {
    /* side set #3  - hex */
    EXCHECK(ex_put_set_param(exoid, EX_SIDE_SET, 32, 7, 0));

    int elem_list[] = {3, 3, 3, 3, 3, 3, 3};
```

```
    int side_list[] = {5, 3, 3, 2, 4, 1, 6};

    EXCHECK(ex_put_set(exoid, EX_SIDE_SET, 32, elem_list, side_list));
  }

  {
    /* side set #4  - tetras */
    EXCHECK(ex_put_set_param(exoid, EX_SIDE_SET, 33, 8, 0));

    int elem_list[] = {4, 4, 4, 4, 6, 6, 6, 6};
    int side_list[] = {1, 2, 3, 4, 1, 2, 3, 4};

    EXCHECK(ex_put_set(exoid, EX_SIDE_SET, 33, elem_list, side_list));
  }

  {
    /* side set #5  - wedges and tris */
    EXCHECK(ex_put_set_param(exoid, EX_SIDE_SET, 34, 10, 0));

    int elem_list[] = {5, 5, 5, 5, 5, 7, 7, 7, 7, 7};
    int side_list[] = {1, 2, 3, 4, 5, 1, 2, 3, 4, 5};

    EXCHECK(ex_put_set(exoid, EX_SIDE_SET, 34, elem_list, side_list));
  }

  /* Write side set names */
  char *sset_names[] = {"sset_1", "sset_2", "sset_3", "sset_4", "sset_5"};
  EXCHECK(ex_put_names(exoid, EX_SIDE_SET, sset_names));
  EXCHECK(ex_put_prop(exoid, EX_SIDE_SET, 30, "COLOR", 100));
  EXCHECK(ex_put_prop(exoid, EX_SIDE_SET, 31, "COLOR", 101));

  /* write QA records; test empty and just blank-filled records */
  int   num_qa_rec = 2;
  char *qa_record[2][4];
  qa_record[0][0] = "TESTWT";
  qa_record[0][1] = "testwt";
  qa_record[0][2] = "07/07/93";
  qa_record[0][3] = "15:41:33";
  qa_record[1][0] = "Thirty-Two␣character␣QA␣Record|";
  qa_record[1][1] = "␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣";
  qa_record[1][2] = "";
  qa_record[1][3] = "␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣";

  EXCHECK(ex_put_qa(exoid, num_qa_rec, qa_record));

  /* write information records; test empty and just blank-filled records */
  char *info[3];
  info[0] = "This␣is␣the␣first␣information␣record.";
  info[1] = "";
  info[2] = "This␣info␣record␣is␣exactly␣80␣characters␣long.␣␣last␣character␣should␣be␣pipe␣

  int num_info = 3;
  EXCHECK(ex_put_info(exoid, num_info, info));

  /* write results variables parameters and names */
```

```
  int num_glo_vars = 1;
  {
    char *var_names[] = {"glo_vars"};

    EXCHECK(ex_put_variable_param(exoid, EX_GLOBAL, num_glo_vars));
    EXCHECK(ex_put_variable_names(exoid, EX_GLOBAL, num_glo_vars, var_names));
  }

  int num_nod_vars = 2;
  {
    /*                     1234567890123456789012345678901 2 */
    char *var_names[] = {"node_variable_a_very_long_name_0", "nod_var1"};

    EXCHECK(ex_put_variable_param(exoid, EX_NODAL, num_nod_vars));
    EXCHECK(ex_put_variable_names(exoid, EX_NODAL, num_nod_vars, var_names));
  }

  int num_ele_vars = 3;
  {
    /* 0        1         2         3   */
    /* 12345678901234567890123456789012 */
    char *var_names[] = {"this_variable_name_is_short",
                         "this_variable_name_is_just_right",
                         "this_variable_name_is_tooooo_long"};

    EXCHECK(ex_put_variable_param(exoid, EX_ELEM_BLOCK, num_ele_vars));
    EXCHECK(ex_put_variable_names(exoid, EX_ELEM_BLOCK, num_ele_vars, var_names));
  }

  int num_nset_vars = 3;
  {
    char *var_names[] = {"ns_var0", "ns_var1", "ns_var2"};

    EXCHECK(ex_put_variable_param(exoid, EX_NODE_SET, num_nset_vars));
    EXCHECK(ex_put_variable_names(exoid, EX_NODE_SET, num_nset_vars, var_names));
  }

  int num_sset_vars = 3;
  {
    char *var_names[] = {"ss_var0", "ss_var1", "ss_var2"};

    EXCHECK(ex_put_variable_param(exoid, EX_SIDE_SET, num_sset_vars));
    EXCHECK(ex_put_variable_names(exoid, EX_SIDE_SET, num_sset_vars, var_names));
  }

  /* write element variable truth table */
  int *truth_tab = (int *)calloc((num_elem_blk * num_ele_vars), sizeof(int));

  {
    int k = 0;
    for (int i = 0; i < num_elem_blk; i++) {
      for (int j = 0; j < num_ele_vars; j++) {
        truth_tab[k++] = 1;
      }
    }
```

```
  }

  EXCHECK(ex_put_truth_table(exoid, EX_ELEM_BLOCK, num_elem_blk,
                             num_ele_vars, truth_tab));
  free(truth_tab);

  /* for each time step, write the analysis results;
   * the code below fills the arrays glob_var_vals,
   * nodal_var_vals, and elem_var_vals with values for debugging purposes;
   * obviously the analysis code will populate these arrays
   */

  float *glob_var_vals  = (float *)calloc(num_glo_vars, CPU_word_size);
  float *nodal_var_vals = (float *)calloc(num_nodes, CPU_word_size);
  float *elem_var_vals  = (float *)calloc(num_ele_vars, CPU_word_size);
  float *sset_var_vals  = (float *)calloc(10, CPU_word_size); /* max sides_in_sset */
  float *nset_var_vals  = (float *)calloc(5, CPU_word_size);  /* max nodes_in_nset */

  int num_time_steps = 10;
  for (int i = 0; i < num_time_steps; i++) {
    int   whole_time_step = i + 1;
    float time_value      = (float)(i + 1) / 100.;

    /* write time value */
    EXCHECK(ex_put_time(exoid, whole_time_step, &time_value));

    /* write global variables */
    for (int j = 0; j < num_glo_vars; j++) {
      glob_var_vals[j] = (float)(j + 2) * time_value;
    }
    EXCHECK(ex_put_var(exoid, whole_time_step, EX_GLOBAL, 1, 1,
                       num_glo_vars, glob_var_vals));

    /* write nodal variables */
    for (int k = 1; k <= num_nod_vars; k++) {
      for (int j = 0; j < num_nodes; j++) {
        nodal_var_vals[j] = (float)k + ((float)(j + 1) * time_value);
      }
      EXCHECK(ex_put_var(exoid, whole_time_step, EX_NODAL, k, 1,
                         num_nodes, nodal_var_vals));
    }

    /* write element variables */
    for (int k = 1; k <= num_ele_vars; k++) {
      for (int j = 0; j < num_elem_blk; j++) {
        for (int m = 0; m < blocks[j].num_entry; m++) {
          elem_var_vals[m] = (float)(k + 1) + (float)(j + 2) + ((float)(m + 1) *
                                                              time_value);
          /* printf("elem_var_vals[%d]: %f\n",m,elem_var_vals[m]); */
        }
        EXCHECK(ex_put_var(exoid, whole_time_step, EX_ELEM_BLOCK, k, blocks[j].id,
                           blocks[j].num_entry, elem_var_vals));
      }
    }

```

```
    /* write sideset variables */
    for (int k = 1; k <= num_sset_vars; k++) {
      for (int j = 0; j < num_side_sets; j++) {
        for (int m = 0; m < num_face_in_sset[j]; m++) {
          sset_var_vals[m] = (float)(k + 2) + (float)(j + 3) +
            ((float)(m + 1) * time_value);
        }
        EXCHECK(ex_put_var(exoid, whole_time_step, EX_SIDE_SET, k, ssids[j],
                           num_face_in_sset[j], sset_var_vals));
      }
    }

    /* write nodeset variables */
    for (int k = 1; k <= num_nset_vars; k++) {
      for (int j = 0; j < num_node_sets; j++) {
        for (int m = 0; m < num_nodes_in_nset[j]; m++) {
          nset_var_vals[m] = (float)(k + 3) + (float)(j + 4) + ((float)(m + 1) *
                                                                 time_value);
        }
        EXCHECK(ex_put_var(exoid, whole_time_step, EX_NODE_SET, k, nsids[j],
                           num_nodes_in_nset[j], nset_var_vals));
      }
    }

    /* update the data file; this should be done at the end of every time step
     * to ensure that no data is lost if the analysis dies
     */
    EXCHECK(ex_update(exoid));
  }
  free(glob_var_vals);
  free(nodal_var_vals);
  free(elem_var_vals);
  free(sset_var_vals);
  free(nset_var_vals);

  /* close the EXODUS files
   */
  EXCHECK(ex_close(exoid));
  return 0;
}
```

C.2 Read Example Code

The following C program reads data from an EXODUS file:

```
/*
 * Copyright(C) 1999-2023 National Technology & Engineering Solutions
 * of Sandia, LLC (NTESS).  Under the terms of Contract DE-NA0003525 with
 * NTESS, the U.S. Government retains certain rights in this software.
 *
 * See packages/seacas/LICENSE for details
 */
#include "exodusII.h"
#include <assert.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
/* #include "drmd.h" */

/* Somewhat cleaner way to check for and report exodus errors... */
#define STRINGIFY(x) #x
#define TOSTRING(x)  STRINGIFY(x)

#define EXCHECK(funcall)                                                  \
  do {                                                                    \
    int f_error = (funcall);                                              \
    printf("after␣%s,␣error␣=␣%d\n", TOSTRING(funcall), f_error);        \
    if (f_error != EX_NOERR && f_error != EX_WARN) {                      \
      fprintf(stderr, "Error␣calling␣%s\n", TOSTRING(funcall));           \
      ex_close(exoid);                                                    \
      exit(-1);                                                           \
    }                                                                     \
  } while (0)
/* End of check */

int main(int argc, char **argv)
{
  ex_opts(EX_VERBOSE | EX_ABORT);

  /* open EXODUS II files */
  float version;
  int   CPU_word_size = 0; /* sizeof(float) */
  int   IO_word_size  = 0; /* use what is stored in file */

  int exoid = ex_open("test.exo",      /* filename path */
                      EX_READ,         /* access mode = READ */
                      &CPU_word_size, /* CPU word size */
                      &IO_word_size,  /* IO word size */
                      &version);      /* ExodusII library version */

  printf("\nafter␣ex_open\n");
  if (exoid < 0) {
    exit(1);
  }

  printf("test.exo␣is␣an␣EXODUSII␣file;␣version␣%4.2f\n", version);
  /*   printf ("         CPU word size %1d\n",CPU_word_size);  */
```

```
  printf("␣␣␣␣␣␣␣␣␣␣I/O␣word␣size␣%1d\n", IO_word_size);
  int   idum;
  char *cdum = NULL;
  ex_inquire(exoid, EX_INQ_API_VERS, &idum, &version, cdum);
  printf("EXODUSII␣API;␣version␣%4.2f\n", version);

  ex_inquire(exoid, EX_INQ_LIB_VERS, &idum, &version, cdum);
  printf("EXODUSII␣Library␣API;␣version␣%4.2f␣(%d)\n", version, idum);

  /* read database parameters */

  char title[MAX_LINE_LENGTH + 1];
  int  num_dim, num_nodes, num_elem, num_elem_blk, num_node_sets;
  int  num_side_sets;
  EXCHECK(ex_get_init(exoid, title, &num_dim, &num_nodes, &num_elem,
                      &num_elem_blk, &num_node_sets, &num_side_sets));

  printf("database␣parameters:\n");
  printf("title␣=␣␣'%s'\n", title);
  printf("num_dim␣=␣%3d\n", num_dim);
  printf("num_nodes␣=␣%3d\n", num_nodes);
  printf("num_elem␣=␣%3d\n", num_elem);
  printf("num_elem_blk␣=␣%3d\n", num_elem_blk);
  printf("num_node_sets␣=␣%3d\n", num_node_sets);
  printf("num_side_sets␣=␣%3d\n", num_side_sets);

  /* Check that ex_inquire gives same title */
  float fdum;
  char  title_chk[MAX_LINE_LENGTH + 1];
  EXCHECK(ex_inquire(exoid, EX_INQ_TITLE, &idum, &fdum, title_chk));
  if (strcmp(title, title_chk) != 0) {
    printf("error␣in␣ex_inquire␣for␣EX_INQ_TITLE\n");
  }

  /* read nodal coordinates values and names from database */
  float *x = (float *)calloc(num_nodes, sizeof(float));
  float *y = (num_dim >= 2) ? (float *)calloc(num_nodes, sizeof(float)) : NULL;
  float *z = (num_dim >= 3) ? (float *)calloc(num_nodes, sizeof(float)) : NULL;

  EXCHECK(ex_get_coord(exoid, x, y, z));

  printf("x␣coords␣=␣\n");
  for (int i = 0; i < num_nodes; i++) {
    printf("%5.1f\n", x[i]);
  }

  if (num_dim >= 2) {
    printf("y␣coords␣=␣\n");
    for (int i = 0; i < num_nodes; i++) {
      printf("%5.1f\n", y[i]);
    }
  }
  if (num_dim >= 3) {
    printf("z␣coords␣=␣\n");
    for (int i = 0; i < num_nodes; i++) {
```

```
      printf("%5.1f\n", z[i]);
    }
  }

  free(x);
  if (num_dim >= 2) {
    free(y);
  }
  if (num_dim >= 3) {
    free(z);
  }

  char *coord_names[3];
  for (int i = 0; i < num_dim; i++) {
    coord_names[i] = (char *)calloc((MAX_STR_LENGTH + 1), sizeof(char));
  }

  EXCHECK(ex_get_coord_names(exoid, coord_names));
  printf("x coord name = '%s'\n", coord_names[0]);
  if (num_dim > 1) {
    printf("y coord name = '%s'\n", coord_names[1]);
  }
  if (num_dim > 2) {
    printf("z coord name = '%s'\n", coord_names[2]);
  }

  for (int i = 0; i < num_dim; i++) {
    free(coord_names[i]);
  }

  {
    int num_attrs = 0;
    EXCHECK(ex_get_attr_param(exoid, EX_NODAL, 0, &num_attrs));
    printf("num nodal attributes = %d\n", num_attrs);
    if (num_attrs > 0) {
      char *attrib_names[10];
      for (int j = 0; j < num_attrs; j++) {
        attrib_names[j] = (char *)calloc((MAX_STR_LENGTH + 1), sizeof(char));
      }
      EXCHECK(ex_get_attr_names(exoid, EX_NODAL, 0, attrib_names));

      float *attrib = (float *)calloc(num_nodes, sizeof(float));
      for (int j = 0; j < num_attrs; j++) {
        printf("nodal attribute %d = '%s'\n", j, attrib_names[j]);
        EXCHECK(ex_get_one_attr(exoid, EX_NODAL, 0, j + 1, attrib));
        for (int i = 0; i < num_nodes; i++) {
          printf("%5.1f\n", attrib[i]);
        }
        free(attrib_names[j]);
      }
      free(attrib);
    }
  }

  /* read element order map */
```

```
  int *elem_map = (int *)calloc(num_elem, sizeof(int));

  EXCHECK(ex_get_id_map(exoid, EX_ELEM_MAP, elem_map));

  for (int i = 0; i < num_elem; i++) {
    printf("elem_id_map(%d) = %d \n", i, elem_map[i]);
  }
  /* NOTE: elem_map used below */

  /* read element block parameters */

  int *num_elem_in_block = NULL;
  if (num_elem_blk > 0) {
    int *ids                = (int *)calloc(num_elem_blk, sizeof(int));
    num_elem_in_block       = (int *)calloc(num_elem_blk, sizeof(int));
    int *num_nodes_per_elem = (int *)calloc(num_elem_blk, sizeof(int));
    int *num_attr           = (int *)calloc(num_elem_blk, sizeof(int));

    EXCHECK(ex_get_ids(exoid, EX_ELEM_BLOCK, ids));

    char *block_names[10];
    for (int i = 0; i < num_elem_blk; i++) {
      block_names[i] = (char *)calloc((MAX_STR_LENGTH + 1), sizeof(char));
    }

    EXCHECK(ex_get_names(exoid, EX_ELEM_BLOCK, block_names));

    for (int i = 0; i < num_elem_blk; i++) {
      char name[MAX_STR_LENGTH + 1];
      ex_get_name(exoid, EX_ELEM_BLOCK, ids[i], name);
      if (strcmp(name, block_names[i]) != 0) {
        printf("error in ex_get_name for block id %d\n", ids[i]);
      }
      char elem_type[MAX_STR_LENGTH + 1];
      EXCHECK(ex_get_block(exoid, EX_ELEM_BLOCK, ids[i], elem_type,
                           &(num_elem_in_block[i]), &(num_nodes_per_elem[i]),
                           0, 0, &(num_attr[i])));

      printf("element block id = %2d\n", ids[i]);
      printf("element type = '%s'\n", elem_type);
      printf("num_elem_in_block = %2d\n", num_elem_in_block[i]);
      printf("num_nodes_per_elem = %2d\n", num_nodes_per_elem[i]);
      printf("num_attr = %2d\n", num_attr[i]);
      printf("name = '%s'\n", block_names[i]);
      free(block_names[i]);
    }

    /* Read per-block id map and compare to overall id map... */
    int offset = 0;
    for (int i = 0; i < num_elem_blk; i++) {
      int *block_map = (int *)calloc(num_elem_in_block[i], sizeof(int));
      EXCHECK(ex_get_block_id_map(exoid, EX_ELEM_BLOCK, ids[i], block_map));

      /* Compare values with overall id map */
```

```
      for (int j = 0; j < num_elem_in_block[i]; j++) {
        assert(block_map[j] == elem_map[offset + j]);
      }
      offset += num_elem_in_block[i];
      free(block_map);
    }

    /* read element block properties */
    int num_props = ex_inquire_int(exoid, EX_INQ_EB_PROP);
    printf("\nThere␣are␣%2d␣properties␣for␣each␣element␣block\n", num_props);

    char *prop_names[3];
    for (int i = 0; i < num_props; i++) {
      prop_names[i] = (char *)calloc((MAX_STR_LENGTH + 1), sizeof(char));
    }

    EXCHECK(ex_get_prop_names(exoid, EX_ELEM_BLOCK, prop_names));

    for (int i = 1; i < num_props; i++) /* Prop 1 is id; skip that here */
    {
      for (int j = 0; j < num_elem_blk; j++) {
        int prop_value;
        EXCHECK(ex_get_prop(exoid, EX_ELEM_BLOCK, ids[j], prop_names[i],
                            &prop_value));
        printf("element␣block␣%2d,␣property(%2d):␣'%s'=␣%5d\n", j + 1, i + 1,
               prop_names[i], prop_value);
      }
    }

    for (int i = 0; i < num_props; i++) {
      free(prop_names[i]);
    }

    /* read element connectivity */

    for (int i = 0; i < num_elem_blk; i++) {
      if (num_elem_in_block[i] > 0) {
        int *connect = (int *)calloc((num_nodes_per_elem[i] * num_elem_in_block[i]), sizeof(

        EXCHECK(ex_get_conn(exoid, EX_ELEM_BLOCK, ids[i], connect, NULL, NULL));
        printf("connect␣array␣for␣elem␣block␣%2d\n", ids[i]);

        for (int j = 0; j < num_nodes_per_elem[i]; j++) {
          printf("%3d\n", connect[j]);
        }
        free(connect);
      }
    }

    /* read element block attributes */
    for (int i = 0; i < num_elem_blk; i++) {
      if (num_elem_in_block[i] > 0 && num_attr[i] > 0) {
        char *attrib_names[10];
        for (int j = 0; j < num_attr[i]; j++) {
          attrib_names[j] = (char *)calloc((MAX_STR_LENGTH + 1), sizeof(char));
```

```
        }

        float *attrib = (float *)calloc(num_attr[i] * num_elem_in_block[i],
                                        sizeof(float));
        EXCHECK(ex_get_attr(exoid, EX_ELEM_BLOCK, ids[i], attrib));

        EXCHECK(ex_get_attr_names(exoid, EX_ELEM_BLOCK, ids[i], attrib_names));
        printf("element block %d attribute '%s' = %6.4f\n", ids[i],
               attrib_names[0], *attrib);

        free(attrib);
        for (int j = 0; j < num_attr[i]; j++) {
          free(attrib_names[j]);
        }
      }
    }

    free(ids);
    free(num_nodes_per_elem);
    free(num_attr);
  }
  free(elem_map);

  /* read individual node sets */
  if (num_node_sets > 0) {
    int *ids = (int *)calloc(num_node_sets, sizeof(int));

    EXCHECK(ex_get_ids(exoid, EX_NODE_SET, ids));

    char *nset_names[10];
    for (int i = 0; i < num_node_sets; i++) {
      nset_names[i] = (char *)calloc((MAX_STR_LENGTH + 1), sizeof(char));
    }

    EXCHECK(ex_get_names(exoid, EX_NODE_SET, nset_names));

    for (int i = 0; i < num_node_sets; i++) {
      char name[MAX_STR_LENGTH + 1];
      ex_get_name(exoid, EX_NODE_SET, ids[i], name);
      if (strcmp(name, nset_names[i]) != 0) {
        printf("error in ex_get_name for nodeset id %d\n", ids[i]);
      }

      int num_nodes_in_set;
      int num_df_in_set;
      EXCHECK(ex_get_set_param(exoid, EX_NODE_SET, ids[i],
                               &num_nodes_in_set, &num_df_in_set));

      printf("\nnode set %2d parameters: \n", ids[i]);
      printf("num_nodes = %2d\n", num_nodes_in_set);
      printf("name = '%s'\n", nset_names[i]);
      free(nset_names[i]);
      int   *node_list = (int *)calloc(num_nodes_in_set, sizeof(int));
      float *dist_fact = (float *)calloc(num_nodes_in_set, sizeof(float));

```

```
      EXCHECK(ex_get_set(exoid, EX_NODE_SET, ids[i], node_list, NULL));

      if (num_df_in_set > 0) {
        EXCHECK(ex_get_set_dist_fact(exoid, EX_NODE_SET, ids[i], dist_fact));
      }

      printf("\nnode␣list␣for␣node␣set␣%2d\n", ids[i]);

      for (int j = 0; j < num_nodes_in_set; j++) {
        printf("%3d\n", node_list[j]);
      }

      if (num_df_in_set > 0) {
        printf("dist␣factors␣for␣node␣set␣%2d\n", ids[i]);

        for (int j = 0; j < num_df_in_set; j++) {
          printf("%5.2f\n", dist_fact[j]);
        }
      }
      else {
        printf("no␣dist␣factors␣for␣node␣set␣%2d\n", ids[i]);
      }

      free(node_list);
      free(dist_fact);

      {
        int num_attrs = 0;
        EXCHECK(ex_get_attr_param(exoid, EX_NODE_SET, ids[i], &num_attrs));
        printf("num␣nodeset␣attributes␣for␣nodeset␣%d␣=␣%d\n",
               ids[i], num_attrs);
        if (num_attrs > 0) {
          char *attrib_names[10];
          for (int j = 0; j < num_attrs; j++) {
            attrib_names[j] = (char *)calloc((MAX_STR_LENGTH + 1),
                                             sizeof(char));
          }
          EXCHECK(ex_get_attr_names(exoid, EX_NODE_SET, ids[i], attrib_names));
          float *attrib = (float *)calloc(num_nodes_in_set, sizeof(float));
          for (int j = 0; j < num_attrs; j++) {
            printf("nodeset␣attribute␣%d␣=␣'%s'\n", j, attrib_names[j]);
            EXCHECK(ex_get_one_attr(exoid, EX_NODE_SET,
                                    ids[i], j + 1, attrib));
            for (int k = 0; k < num_nodes_in_set; k++) {
              printf("%5.1f\n", attrib[k]);
            }
            free(attrib_names[j]);
          }
          free(attrib);
        }
      }
    }
    free(ids);

    /* read node set properties */
```

```
    int num_props = ex_inquire_int(exoid, EX_INQ_NS_PROP);
    printf("\nThere are %2d properties for each node set\n", num_props);

    char *prop_names[10];
    for (int i = 0; i < num_props; i++) {
      prop_names[i] = (char *)calloc((MAX_STR_LENGTH + 1), sizeof(char));
    }
    int *prop_values = (int *)calloc(num_node_sets, sizeof(int));

    EXCHECK(ex_get_prop_names(exoid, EX_NODE_SET, prop_names));

    for (int i = 0; i < num_props; i++) {
      EXCHECK(ex_get_prop_array(exoid, EX_NODE_SET, prop_names[i],
                                prop_values));
      for (int j = 0; j < num_node_sets; j++) {
        printf("node set %2d, property(%2d): '%s'= %5d\n", j + 1, i + 1,
               prop_names[i], prop_values[j]);
      }
    }
    for (int i = 0; i < num_props; i++) {
      free(prop_names[i]);
    }
    free(prop_values);
  }
  /* read concatenated node sets; this produces the same information as
   * the above code which reads individual node sets
   */

  int *num_nodes_per_set = NULL;
  if (num_node_sets > 0) {
    int *ids             = (int *)calloc(num_node_sets, sizeof(int));
    num_nodes_per_set    = (int *)calloc(num_node_sets, sizeof(int));
    int *num_df_per_set  = (int *)calloc(num_node_sets, sizeof(int));
    int *node_ind        = (int *)calloc(num_node_sets, sizeof(int));
    int *df_ind          = (int *)calloc(num_node_sets, sizeof(int));

    int  list_len  = ex_inquire_int(exoid, EX_INQ_NS_NODE_LEN);
    int *node_list = (int *)calloc(list_len, sizeof(int));

    list_len          = ex_inquire_int(exoid, EX_INQ_NS_DF_LEN);
    float *dist_fact = (float *)calloc(list_len, sizeof(float));

    {
      struct ex_set_specs set_specs;

      set_specs.sets_ids            = ids;
      set_specs.num_entries_per_set = num_nodes_per_set;
      set_specs.num_dist_per_set    = num_df_per_set;
      set_specs.sets_entry_index    = node_ind;
      set_specs.sets_dist_index     = df_ind;
      set_specs.sets_entry_list     = node_list;
      set_specs.sets_extra_list     = NULL;
      set_specs.sets_dist_fact      = dist_fact;

      EXCHECK(ex_get_concat_sets(exoid, EX_NODE_SET, &set_specs));
```

```
    }
    printf("\nconcatenated␣node␣set␣info\n");

    printf("ids␣=␣\n");
    for (int i = 0; i < num_node_sets; i++) {
      printf("%3d\n", ids[i]);
    }

    printf("num_nodes_per_set␣=␣\n");
    for (int i = 0; i < num_node_sets; i++) {
      printf("%3d\n", num_nodes_per_set[i]);
    }

    printf("node_ind␣=␣\n");
    for (int i = 0; i < num_node_sets; i++) {
      printf("%3d\n", node_ind[i]);
    }

    printf("node_list␣=␣\n");
    for (int i = 0; i < list_len; i++) {
      printf("%3d\n", node_list[i]);
    }

    printf("dist_fact␣=␣\n");
    for (int i = 0; i < list_len; i++) {
      printf("%5.3f\n", dist_fact[i]);
    }

    free(ids);
    free(df_ind);
    free(node_ind);
    free(num_df_per_set);
    free(node_list);
    free(dist_fact);
  }

  /* read individual side sets */
  if (num_side_sets > 0) {
    int *ids = (int *)calloc(num_side_sets, sizeof(int));

    EXCHECK(ex_get_ids(exoid, EX_SIDE_SET, ids));

    char *sset_names[10];
    for (int i = 0; i < num_side_sets; i++) {
      sset_names[i] = (char *)calloc((MAX_STR_LENGTH + 1), sizeof(char));
    }

    EXCHECK(ex_get_names(exoid, EX_SIDE_SET, sset_names));

    for (int i = 0; i < num_side_sets; i++) {
      char name[MAX_STR_LENGTH + 1];
      ex_get_name(exoid, EX_SIDE_SET, ids[i], name);
      if (strcmp(name, sset_names[i]) != 0) {
        printf("error␣in␣ex_get_name␣for␣sideset␣id␣%d\n", ids[i]);
      }
```

```
      int num_sides_in_set;
      int num_df_in_set;
      EXCHECK(ex_get_set_param(exoid, EX_SIDE_SET, ids[i],
                               &num_sides_in_set, &num_df_in_set));

      printf("side␣set␣%2d␣parameters:\n", ids[i]);
      printf("name␣=␣'%s'\n", sset_names[i]);
      printf("num_sides␣=␣%3d\n", num_sides_in_set);
      printf("num_dist_factors␣=␣%3d\n", num_df_in_set);
      free(sset_names[i]);

      /* Note: The # of elements is same as # of sides!  */
      int    num_elem_in_set = num_sides_in_set;
      int   *elem_list       = (int *)calloc(num_elem_in_set, sizeof(int));
      int   *side_list       = (int *)calloc(num_sides_in_set, sizeof(int));
      int   *node_ctr_list   = (int *)calloc(num_elem_in_set, sizeof(int));
      int   *node_list       = (int *)calloc(num_elem_in_set * 21, sizeof(int));
      float *dist_fact       = (float *)calloc(num_df_in_set, sizeof(float));

      EXCHECK(ex_get_set(exoid, EX_SIDE_SET, ids[i], elem_list, side_list));
      EXCHECK(ex_get_side_set_node_list(exoid, ids[i], node_ctr_list, node_list));

      if (num_df_in_set > 0) {
        EXCHECK(ex_get_set_dist_fact(exoid, EX_SIDE_SET, ids[i], dist_fact));
      }

      printf("element␣list␣for␣side␣set␣%2d\n", ids[i]);
      for (int j = 0; j < num_elem_in_set; j++) {
        printf("%3d\n", elem_list[j]);
      }

      printf("side␣list␣for␣side␣set␣%2d\n", ids[i]);
      for (int j = 0; j < num_sides_in_set; j++) {
        printf("%3d\n", side_list[j]);
      }

      int node_ctr = 0;
      printf("node␣list␣for␣side␣set␣%2d\n", ids[i]);
      for (int k = 0; k < num_elem_in_set; k++) {
        for (int j = 0; j < node_ctr_list[k]; j++) {
          printf("%3d\n", node_list[node_ctr + j]);
        }
        node_ctr += node_ctr_list[k];
      }

      if (num_df_in_set > 0) {
        printf("dist␣factors␣for␣side␣set␣%2d\n", ids[i]);

        for (int j = 0; j < num_df_in_set; j++) {
          printf("%5.3f\n", dist_fact[j]);
        }
      }
      else {
        printf("no␣dist␣factors␣for␣side␣set␣%2d\n", ids[i]);
```

```
      }

      free(elem_list);
      free(side_list);
      free(node_ctr_list);
      free(node_list);
      free(dist_fact);
    }

    /* read side set properties */
    int num_props = ex_inquire_int(exoid, EX_INQ_SS_PROP);
    printf("\nThere␣are␣%2d␣properties␣for␣each␣side␣set\n", num_props);

    char *prop_names[10];
    for (int i = 0; i < num_props; i++) {
      prop_names[i] = (char *)calloc((MAX_STR_LENGTH + 1), sizeof(char));
    }

    EXCHECK(ex_get_prop_names(exoid, EX_SIDE_SET, prop_names));

    for (int i = 0; i < num_props; i++) {
      for (int j = 0; j < num_side_sets; j++) {
        int prop_value;
        EXCHECK(ex_get_prop(exoid, EX_SIDE_SET, ids[j], prop_names[i],
                            &prop_value));
        printf("side␣set␣%2d,␣property(%2d):␣'%s'=␣%5d\n", j + 1, i + 1,
               prop_names[i], prop_value);
      }
    }
    for (int i = 0; i < num_props; i++) {
      free(prop_names[i]);
    }
    free(ids);
  }

  int *num_elem_per_set = NULL;
  if (num_side_sets > 0) {
    int elem_list_len = ex_inquire_int(exoid, EX_INQ_SS_ELEM_LEN);
    printf("\nafter␣ex_inquire:␣EX_INQ_SS_ELEM_LEN␣=␣%d\n", elem_list_len);

    int node_list_len = ex_inquire_int(exoid, EX_INQ_SS_NODE_LEN);
    printf("\nafter␣ex_inquire:␣EX_INQ_SS_NODE_LEN␣=␣%d\n", node_list_len);

    int df_list_len = ex_inquire_int(exoid, EX_INQ_SS_DF_LEN);
    printf("\nafter␣ex_inquire:␣EX_INQ_SS_DF_LEN␣=␣%d\n", df_list_len);

    /* read concatenated side sets; this produces the same information as
     * the above code which reads individual side sets
     */

    /* concatenated side set read */

    struct ex_set_specs set_specs;

    int *ids              = (int *)calloc(num_side_sets, sizeof(int));
```

```
    num_elem_per_set       = (int *)calloc(num_side_sets, sizeof(int));
    int   *num_df_per_set = (int *)calloc(num_side_sets, sizeof(int));
    int   *elem_ind       = (int *)calloc(num_side_sets, sizeof(int));
    int   *df_ind         = (int *)calloc(num_side_sets, sizeof(int));
    int   *elem_list      = (int *)calloc(elem_list_len, sizeof(int));
    int   *side_list      = (int *)calloc(elem_list_len, sizeof(int));
    float *dist_fact      = (float *)calloc(df_list_len, sizeof(float));

    set_specs.sets_ids             = ids;
    set_specs.num_entries_per_set = num_elem_per_set;
    set_specs.num_dist_per_set    = num_df_per_set;
    set_specs.sets_entry_index    = elem_ind;
    set_specs.sets_dist_index     = df_ind;
    set_specs.sets_entry_list     = elem_list;
    set_specs.sets_extra_list     = side_list;
    set_specs.sets_dist_fact      = dist_fact;

    EXCHECK(ex_get_concat_sets(exoid, EX_SIDE_SET, &set_specs));

    printf("concatenated side set info\n");

    printf("ids = \n");
    for (int i = 0; i < num_side_sets; i++) {
      printf("%3d\n", ids[i]);
    }

    printf("num_elem_per_set = \n");
    for (int i = 0; i < num_side_sets; i++) {
      printf("%3d\n", num_elem_per_set[i]);
    }

    printf("num_dist_per_set = \n");
    for (int i = 0; i < num_side_sets; i++) {
      printf("%3d\n", num_df_per_set[i]);
    }

    printf("elem_ind = \n");
    for (int i = 0; i < num_side_sets; i++) {
      printf("%3d\n", elem_ind[i]);
    }

    printf("dist_ind = \n");
    for (int i = 0; i < num_side_sets; i++) {
      printf("%3d\n", df_ind[i]);
    }

    printf("elem_list = \n");
    for (int i = 0; i < elem_list_len; i++) {
      printf("%3d\n", elem_list[i]);
    }

    printf("side_list = \n");
    for (int i = 0; i < elem_list_len; i++) {
      printf("%3d\n", side_list[i]);
    }
```

```c

    printf("dist_fact␣=␣\n");
    for (int i = 0; i < df_list_len; i++) {
      printf("%5.3f\n", dist_fact[i]);
    }

    free(ids);
    free(num_df_per_set);
    free(df_ind);
    free(elem_ind);
    free(elem_list);
    free(side_list);
    free(dist_fact);
  }
  /* end of concatenated side set read */

  /* read QA records */

  int num_qa_rec = ex_inquire_int(exoid, EX_INQ_QA);

  char *qa_record[2][4];
  for (int i = 0; i < num_qa_rec; i++) {
    for (int j = 0; j < 4; j++) {
      qa_record[i][j] = (char *)calloc((MAX_STR_LENGTH + 1), sizeof(char));
    }
  }

  EXCHECK(ex_get_qa(exoid, qa_record));
  printf("QA␣records␣=␣\n");
  for (int i = 0; i < num_qa_rec; i++) {
    for (int j = 0; j < 4; j++) {
      printf("␣'%s'\n", qa_record[i][j]);
      free(qa_record[i][j]);
    }
  }

  /* read information records */

  int num_info = ex_inquire_int(exoid, EX_INQ_INFO);

  char *info[3];
  for (int i = 0; i < num_info; i++) {
    info[i] = (char *)calloc((MAX_LINE_LENGTH + 1), sizeof(char));
  }

  EXCHECK(ex_get_info(exoid, info));

  printf("info␣records␣=␣\n");
  for (int i = 0; i < num_info; i++) {
    printf("␣'%s'\n", info[i]);
    free(info[i]);
  }

  /* read global variables parameters and names */

```

```
  int num_glo_vars;
  EXCHECK(ex_get_variable_param(exoid, EX_GLOBAL, &num_glo_vars));

  if (num_glo_vars > 0) {
    char *var_names[3];
    for (int i = 0; i < num_glo_vars; i++) {
      var_names[i] = (char *)calloc((MAX_STR_LENGTH + 1), sizeof(char));
    }

    EXCHECK(ex_get_variable_names(exoid, EX_GLOBAL, num_glo_vars, var_names));
    printf("There are %2d global variables; their names are :\n", num_glo_vars);
    for (int i = 0; i < num_glo_vars; i++) {
      printf(" '%s'\n", var_names[i]);
      free(var_names[i]);
    }
  }

  /* read nodal variables parameters and names */
  int num_nod_vars = 0;
  if (num_nodes > 0) {
    EXCHECK(ex_get_variable_param(exoid, EX_NODAL, &num_nod_vars));

    char *var_names[3];
    for (int i = 0; i < num_nod_vars; i++) {
      var_names[i] = (char *)calloc((MAX_STR_LENGTH + 1), sizeof(char));
    }

    EXCHECK(ex_get_variable_names(exoid, EX_NODAL, num_nod_vars, var_names));
    printf("There are %2d nodal variables; their names are :\n", num_nod_vars);
    for (int i = 0; i < num_nod_vars; i++) {
      printf(" '%s'\n", var_names[i]);
      free(var_names[i]);
    }
  }

  /* read element variables parameters and names */

  int num_ele_vars = 0;
  if (num_elem > 0) {
    EXCHECK(ex_get_variable_param(exoid, EX_ELEM_BLOCK, &num_ele_vars));
    char *var_names[3];
    for (int i = 0; i < num_ele_vars; i++) {
      var_names[i] = (char *)calloc((MAX_STR_LENGTH + 1), sizeof(char));
    }

    EXCHECK(ex_get_variable_names(exoid, EX_ELEM_BLOCK, num_ele_vars, var_names));
    printf("There are %2d element variables; their names are :\n", num_ele_vars);
    for (int i = 0; i < num_ele_vars; i++) {
      printf(" '%s'\n", var_names[i]);
      free(var_names[i]);
    }

    /* read element variable truth table */

    if (num_ele_vars > 0) {
```

```
      int *truth_tab = (int *)calloc((num_elem_blk * num_ele_vars), sizeof(int));

      EXCHECK(ex_get_truth_table(exoid, EX_ELEM_BLOCK, num_elem_blk,
                                 num_ele_vars, truth_tab));
      printf("This␣is␣the␣element␣variable␣truth␣table:\n");
      for (int i = 0; i < num_elem_blk * num_ele_vars; i++) {
        printf("%2d\n", truth_tab[i]);
      }
      free(truth_tab);
    }
  }

  /* read nodeset variables parameters and names */

  int num_nset_vars = 0;
  if (num_node_sets > 0) {
    EXCHECK(ex_get_variable_param(exoid, EX_NODE_SET, &num_nset_vars));
    if (num_nset_vars > 0) {
      char *var_names[3];
      for (int i = 0; i < num_nset_vars; i++) {
        var_names[i] = (char *)calloc((MAX_STR_LENGTH + 1), sizeof(char));
      }

      EXCHECK(ex_get_variable_names(exoid, EX_NODE_SET, num_nset_vars, var_names));
      printf("There␣are␣%2d␣nodeset␣variables;␣their␣names␣are␣:\n", num_nset_vars);
      for (int i = 0; i < num_nset_vars; i++) {
        printf("␣'%s'\n", var_names[i]);
        free(var_names[i]);
      }

      /* read nodeset variable truth table */

      if (num_nset_vars > 0) {
        int *truth_tab = (int *)calloc((num_node_sets * num_nset_vars), sizeof(int));

        EXCHECK(ex_get_truth_table(exoid, EX_NODE_SET, num_node_sets,
                                   num_nset_vars, truth_tab));
        printf("This␣is␣the␣nodeset␣variable␣truth␣table:\n");
        for (int i = 0; i < num_node_sets * num_nset_vars; i++) {
          printf("%2d\n", truth_tab[i]);
        }
        free(truth_tab);
      }
    }
  }

  /* read sideset variables parameters and names */
  int num_sset_vars = 0;
  if (num_side_sets > 0) {
    EXCHECK(ex_get_variable_param(exoid, EX_SIDE_SET, &num_sset_vars));
    if (num_sset_vars > 0) {
      char *var_names[3];
      for (int i = 0; i < num_sset_vars; i++) {
        var_names[i] = (char *)calloc((MAX_STR_LENGTH + 1), sizeof(char));
      }
```

```
    EXCHECK(ex_get_variable_names(exoid, EX_SIDE_SET, num_sset_vars, var_names));
    printf("There␣are␣%2d␣sideset␣variables;␣their␣names␣are␣:\n", num_sset_vars);
    for (int i = 0; i < num_sset_vars; i++) {
      printf("␣'%s'\n", var_names[i]);
      free(var_names[i]);
    }

    /* read sideset variable truth table */

    if (num_sset_vars > 0) {
      int *truth_tab = (int *)calloc((num_side_sets * num_sset_vars), sizeof(int));

      EXCHECK(ex_get_truth_table(exoid, EX_SIDE_SET, num_side_sets,
                                 num_sset_vars, truth_tab));
      printf("This␣is␣the␣sideset␣variable␣truth␣table:\n");
      for (int i = 0; i < num_side_sets * num_sset_vars; i++) {
        printf("%2d\n", truth_tab[i]);
      }
      free(truth_tab);
    }
  }
}

/* determine how many time steps are stored */
int num_time_steps = ex_inquire_int(exoid, EX_INQ_TIME);
printf("There␣are␣%2d␣time␣steps␣in␣the␣database.\n", num_time_steps);

/* read time value at one time step */

int   time_step = 3;
float time_value;
EXCHECK(ex_get_time(exoid, time_step, &time_value));
printf("time␣value␣at␣time␣step␣%2d␣=␣%5.3f\n", time_step, time_value);

/* read time values at all time steps */
float *time_values = (float *)calloc(num_time_steps, sizeof(float));
EXCHECK(ex_get_all_times(exoid, time_values));
printf("time␣values␣at␣all␣time␣steps␣are:\n");
for (int i = 0; i < num_time_steps; i++) {
  printf("%5.3f\n", time_values[i]);
}

free(time_values);

/* read all global variables at one time step */
int var_index = 1;
int beg_time  = 1;
int end_time  = -1;

if (num_glo_vars > 0) {
  float *var_values = (float *)calloc(num_glo_vars, sizeof(float));

  EXCHECK(ex_get_var(exoid, time_step, EX_GLOBAL, 1, 1, num_glo_vars,
                     var_values));
```

```
    printf("global␣variable␣values␣at␣time␣step␣%2d\n", time_step);
    for (int i = 0; i < num_glo_vars; i++) {
      printf("%5.3f\n", var_values[i]);
    }

    free(var_values);

    /* read a single global variable through time */
    var_values = (float *)calloc(num_time_steps, sizeof(float));
    EXCHECK(ex_get_var_time(exoid, EX_GLOBAL, var_index, 1, beg_time, end_time,
                            var_values));
    printf("global␣variable␣%2d␣values␣through␣time:\n", var_index);
    for (int i = 0; i < num_time_steps; i++) {
      printf("%5.3f\n", var_values[i]);
    }

    free(var_values);
  }

  /* read a nodal variable at one time step */
  if (num_nodes > 0) {
    float *var_values = (float *)calloc(num_nodes, sizeof(float));
    EXCHECK(ex_get_var(exoid, time_step, EX_NODAL, var_index, 1,
                       num_nodes, var_values));
    printf("nodal␣variable␣%2d␣values␣at␣time␣step␣%2d\n",
           var_index, time_step);
    for (int i = 0; i < num_nodes; i++) {
      printf("%5.3f\n", var_values[i]);
    }

    free(var_values);

    /* read a nodal variable through time */
    var_values = (float *)calloc(num_time_steps, sizeof(float));

    int node_num = 1;
    EXCHECK(ex_get_var_time(exoid, EX_NODAL, var_index, node_num,
                            beg_time, end_time, var_values));
    printf("nodal␣variable␣%2d␣values␣for␣node␣%2d␣through␣time:\n",
           var_index, node_num);
    for (int i = 0; i < num_time_steps; i++) {
      printf("%5.3f\n", var_values[i]);
    }

    free(var_values);
  }
  /* read an element variable at one time step */

  if (num_elem_blk > 0) {
    int *ids = (int *)calloc(num_elem_blk, sizeof(int));

    EXCHECK(ex_get_ids(exoid, EX_ELEM_BLOCK, ids));
    for (int i = 0; i < num_elem_blk; i++) {
      if (num_elem_in_block[i] > 0) {
        float *var_values = (float *)calloc(num_elem_in_block[i], sizeof(float));
```

```

      EXCHECK(ex_get_var(exoid, time_step, EX_ELEM_BLOCK, var_index, ids[i],
                         num_elem_in_block[i],
                         var_values));
      printf("element␣variable␣%2d␣values␣of␣element␣block␣%2d␣at␣time␣step␣%2d\n",
             var_index, ids[i], time_step);
      for (int j = 0; j < num_elem_in_block[i]; j++) {
        printf("%5.3f\n", var_values[j]);
      }
      free(var_values);
    }
  }
  free(num_elem_in_block);
  free(ids);
}
/* read an element variable through time */

if (num_ele_vars > 0) {
  float *var_values = (float *)calloc(num_time_steps, sizeof(float));

  var_index    = 2;
  int elem_num = 2;
  EXCHECK(
      ex_get_var_time(exoid, EX_ELEM_BLOCK, var_index, elem_num,
                      beg_time, end_time, var_values));
  printf("element␣variable␣%2d␣values␣for␣element␣%2d␣through␣time:\n",
         var_index, elem_num);
  for (int i = 0; i < num_time_steps; i++) {
    printf("%5.3f\n", var_values[i]);
  }

  free(var_values);
}

/* read a sideset variable at one time step */

if (num_sset_vars > 0) {
  int *ids = (int *)calloc(num_side_sets, sizeof(int));

  EXCHECK(ex_get_ids(exoid, EX_SIDE_SET, ids));
  for (int i = 0; i < num_side_sets; i++) {
    float *var_values = (float *)calloc(num_elem_per_set[i], sizeof(float));

    EXCHECK(ex_get_var(exoid, time_step, EX_SIDE_SET, var_index, ids[i],
                       num_elem_per_set[i], var_values));
    printf("sideset␣variable␣%2d␣values␣of␣sideset␣%2d␣at␣time␣step␣%2d\n",
           var_index, ids[i], time_step);
    for (int j = 0; j < num_elem_per_set[i]; j++) {
      printf("%5.3f\n", var_values[j]);
    }
    free(var_values);
  }
  free(ids);
}
free(num_elem_per_set);
```

```

  /* read a nodeset variable at one time step */

  if (num_nset_vars > 0) {
    int *ids = (int *)calloc(num_node_sets, sizeof(int));

    EXCHECK(ex_get_ids(exoid, EX_NODE_SET, ids));
    for (int i = 0; i < num_node_sets; i++) {
      float *var_values = (float *)calloc(num_nodes_per_set[i], sizeof(float));

      EXCHECK(ex_get_var(exoid, time_step, EX_NODE_SET, var_index, ids[i],
                         num_nodes_per_set[i], var_values));
      printf("nodeset variable %2d values of nodeset %2d at time step %2d\n",
             var_index, ids[i], time_step);
      for (int j = 0; j < num_nodes_per_set[i]; j++) {
        printf("%5.3f\n", var_values[j]);
      }
      free(var_values);
    }
    free(ids);
  }
  if (num_node_sets > 0) {
    free(num_nodes_per_set);
  }

  EXCHECK(ex_close(exoid));
  return 0;
}
```

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