

CGNS/SIDS proposal for extensions

Authors: Meilin Yu and Z. J. Wang, the University of Kansas

Contact: zjw@ku.edu

Implementation of quartic elements for unstructured zones

The proposal is an extension of the element structure definition (*Elements_t*) for unstructured zones. We propose to add quartic elements to *ElementType*. This extension can enhance the performance of CGNS in handling high-order (≥ 2) elements which are widely used in high-order CFD simulations. Moreover, this extension can further strengthen the capability of CGNS on accurate presentation of complex geometry, especially when a coarse grid is provided.

The new quartic element types proposed are summarized as follows.

Dimensionality of the Element	Shape	Cubic Interpolation
1-D	Line	BAR_5
2-D	Triangle	TRI_12, TRI_15
	Quadrangle	QUAD_P4_16*, QUAD_25
3-D	Tetrahedron	TETRA_22, TETRA_34, TETRA_35
	Pyramid	PYRA_P4_29*, PYRA_50, PYRA_55
	Pentahedron	PENTA_33, PENTA_66, PENTA_75
	Hexahedron	HEXA_44, HEXA_98, HEXA_125

*: 'P4' is assigned to distinguish the corresponding cubic elements of the same number of points.

The element numbering convention is specified as follows.

Note that 'N' stands for grid point identification number. 'E' indicates edge identification number. A negative edge means that the edge is used in its reverse direction. 'F' stands for face identification number.

1. 1-D Element



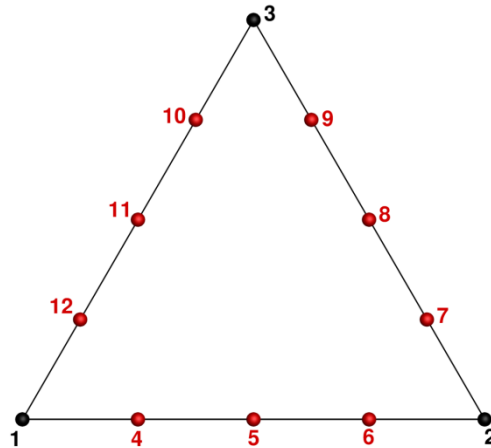
BAR_5

Edge Definition

Oriented edges	Corner nodes	Mid-nodes
E1	N1,N2	N3,N4,N5

2. 2-D (Surface) Element

2.1 Triangular Element



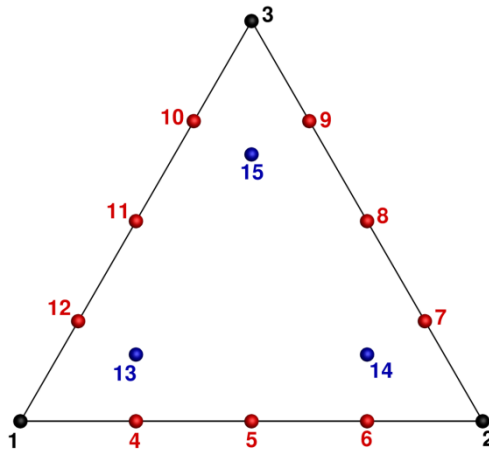
TRI_12

Edge Definition

Oriented edges	Corner nodes	Mid-nodes
E1	N1,N2	N4,N5,N6
E2	N2,N3	N7,N8,N9
E3	N3,N1	N10,N11,N12

Face Definition

Oriented edges	Corner nodes	Mid-edge nodes	Oriented edges
F1	N1,N2,N3	N4,N5,N6,N7,N8,N9,N10,N11,N12	E1,E2,E3



TRI_15

Location of mid-face nodes

N13 is located at the centroid of sub-triangle N1-N5-N11; N14 is located at the centroid of sub-triangle N2-N8-N5; N15 is located at the centroid of sub-triangle N3-N11-N8.

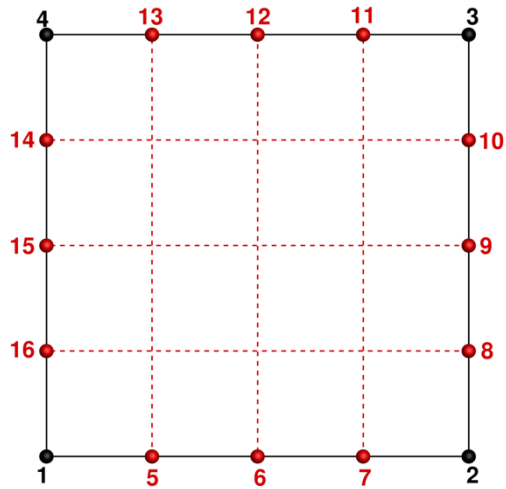
Edge Definition

Oriented edges	Corner nodes	Mid-nodes
E1	N1,N2	N4,N5,N6
E2	N2,N3	N7,N8,N9
E3	N3,N1	N10,N11,N12

Face Definition

Oriented edges	Corner nodes	Mid-edge nodes	Mid-face nodes	Oriented edges
F1	N1,N2,N3	N4,N5,N6,N7,N8,N9, N10,N11,N12	N13,N14,N15	E1,E2,E3

2.2 Quadrilateral Element



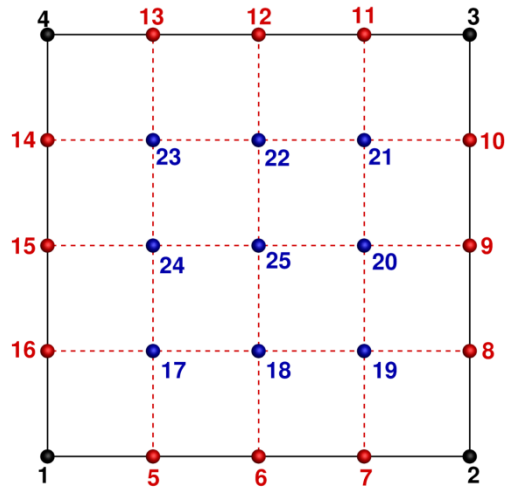
QUAD_P4_16

Edge Definition

Oriented edges	Corner nodes	Mid-nodes
E1	N1,N2	N5,N6,N7
E2	N2,N3	N8,N9,N10
E3	N3,N4	N11,N12,N13
E4	N4,N1	N14,N15,N16

Face Definition

Oriented edges	Corner nodes	Mid-edge nodes	Oriented edges
F1	N1,N2,N3,N4	N5,N6,N7,N8,N9, N10,N11,N12,N13, N14,N15,N16	E1,E2,E3,E4



QUAD_25

Edge Definition

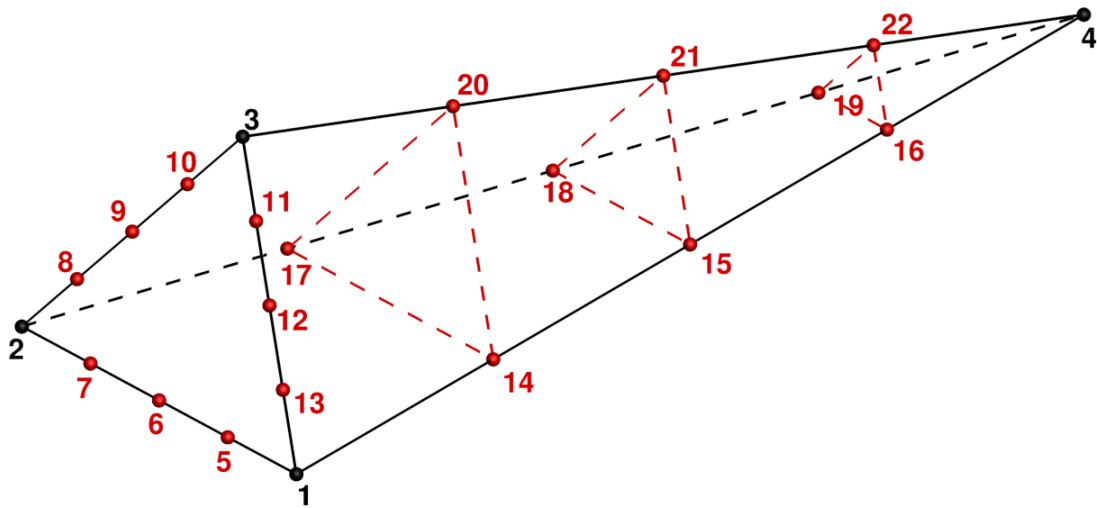
Oriented edges	Corner nodes	Mid-nodes
E1	N1,N2	N5,N6,N7
E2	N2,N3	N8,N9,N10
E3	N3,N4	N11,N12,N13
E4	N4,N1	N14,N15,N16

Face Definition

Oriented edges	Corner nodes	Mid-edge nodes	Mid-face nodes	Oriented edges
F1	N1,N2,N3,N4	N5,N6,N7,N8,N9, N10,N11,N12,N13 N14,N15,N16	N17,N18,N19, N20,N21,N22, N23,N24,N25	E1,E2,E3

3. 3-D (Volume) Element

3.1 Tetrahedral Element



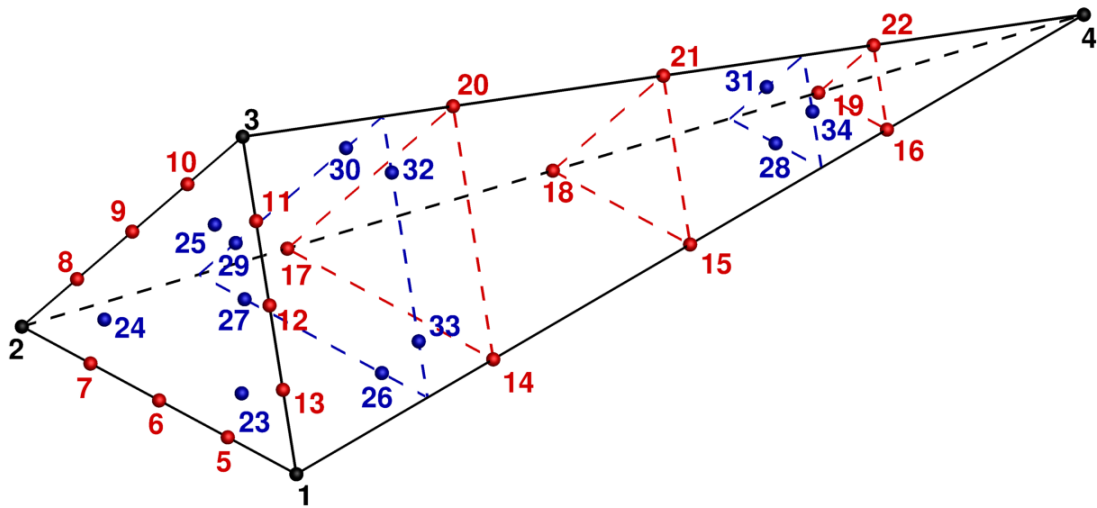
TETRA_22

Edge Definition

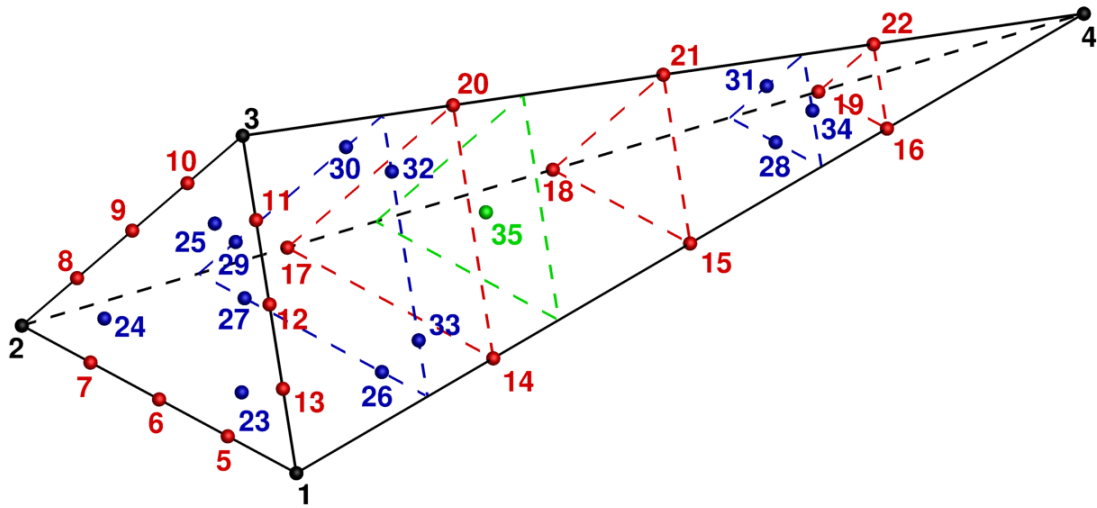
Oriented edges	Corner nodes	Mid-nodes
E1	N1,N2	N5,N6,N7
E2	N2,N3	N8,N9,N10
E3	N3,N1	N11,N12,N13
E4	N1,N4	N14,N15,N16
E5	N2,N4	N17,N18,N19
E6	N3,N4	N20,N21,N22

Face Definition

Oriented edges	Corner nodes	Mid-edge nodes	Oriented edges
F1	N1,N3,N2	N13,N12,N11,N10,N9,N8,N7,N6,N5	-E3,-E2,-E1
F2	N1,N2,N4	N5,N6,N7,N17,N18,N19,N16,N15,N14	E1,E5,-E4
F3	N2,N3,N4	N8,N9,N10,N20,N21,N22,N19,N18,N17	E2,E6,-E5
F4	N3,N1,N4	N11,N12,N13,N14,N15,N16,N22,N21,N20	E3,E4,-E6



TETRA_34



TETRA_35

Location of mid-face nodes

N23 is located at the centroid of sub-triangle N1-N12-N6; N24 is located at the centroid of sub-triangle N2-N6-N9; N25 is located at the centroid of sub-triangle N3-N9-N12; N26 is located at the centroid of sub-triangle N1-N6-N15; N27 is located at the centroid of sub-triangle N2-N18-N6; N28 is located at the centroid of sub-triangle N4-N15-N18; N29 is located at the centroid of sub-triangle N2-N9-N18; N30 is located at the centroid of sub-triangle N3-N21-N9; N31 is located at the centroid of sub-triangle N4-N18-N21; N32 is located at the centroid of sub-triangle N3-N12-N21; N33 is located at the centroid of sub-triangle N1-N15-N12; N34 is located at the centroid of sub-triangle N4-N21-N15.

Location of volume nodes

N35 is located at the centroid of the tetrahedron.

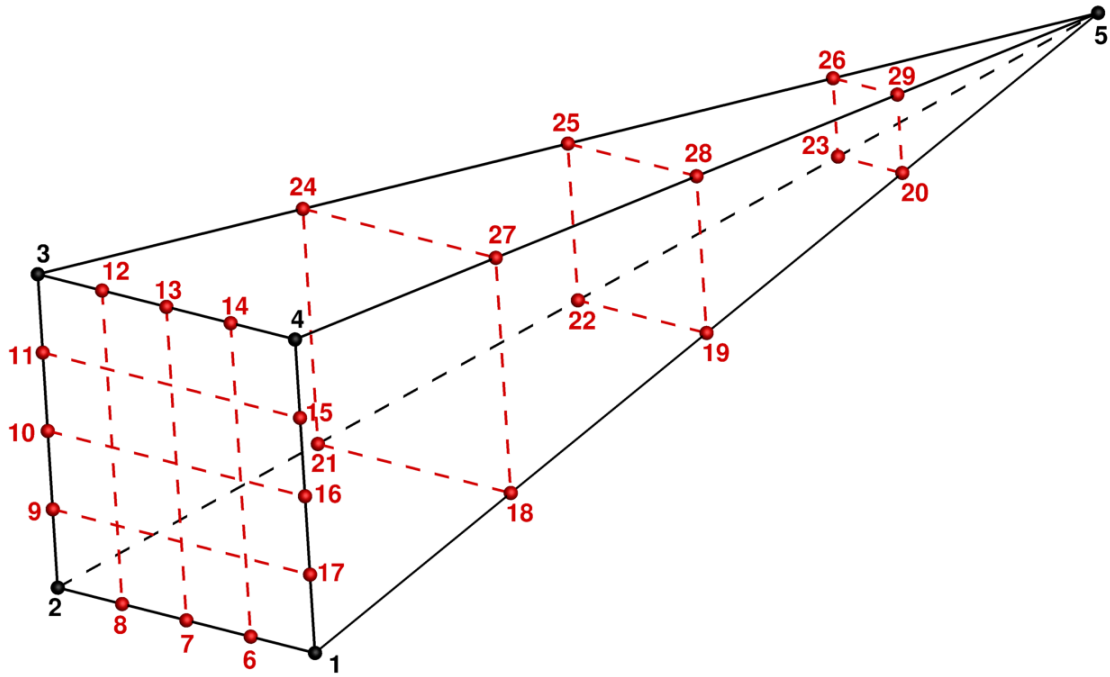
Edge Definition

Oriented edges	Corner nodes	Mid-nodes
E1	N1,N2	N5,N6,N7
E2	N2,N3	N8,N9,N10
E3	N3,N1	N11,N12,N13
E4	N1,N4	N14,N15,N16
E5	N2,N4	N17,N18,N19
E6	N3,N4	N20,N21,N22

Face Definition

Oriented edges	Corner nodes	Mid-edge nodes	Mid-face nodes	Oriented edges
F1	N1,N3,N2	N13,N12,N11,N10,N9, N8,N7,N6,N5	N23,N24,N25	-E3,-E2,-E1
F2	N1,N2,N4	N5,N6,N7,N17,N18, N19,N16,N15,N14	N26,N27,N28	E1,E5,-E4
F3	N2,N3,N4	N8,N9,N10,N20,N21, N22,N19,N18,N17	N29,N30,N31	E2,E6,-E5
F4	N3,N1,N4	N11,N12,N13,N14,N15, N16,N22,N21,N20	N32,N33,N34	E3,E4,-E6

3.2 Pyramid Element



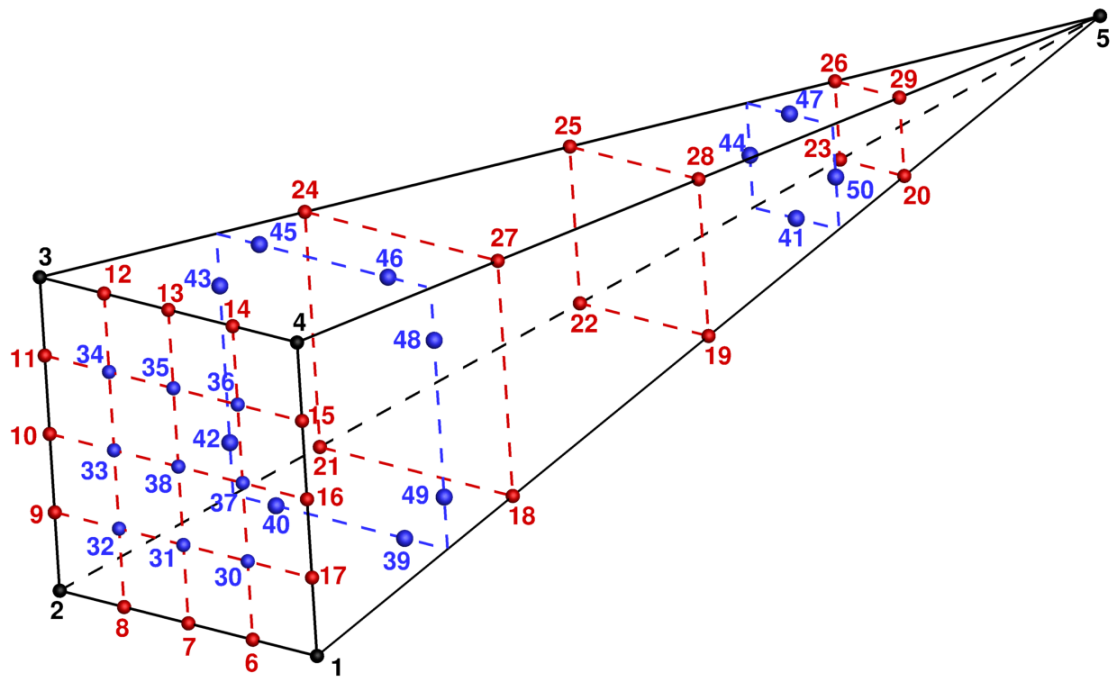
PYRA_P4_29

Edge Definition

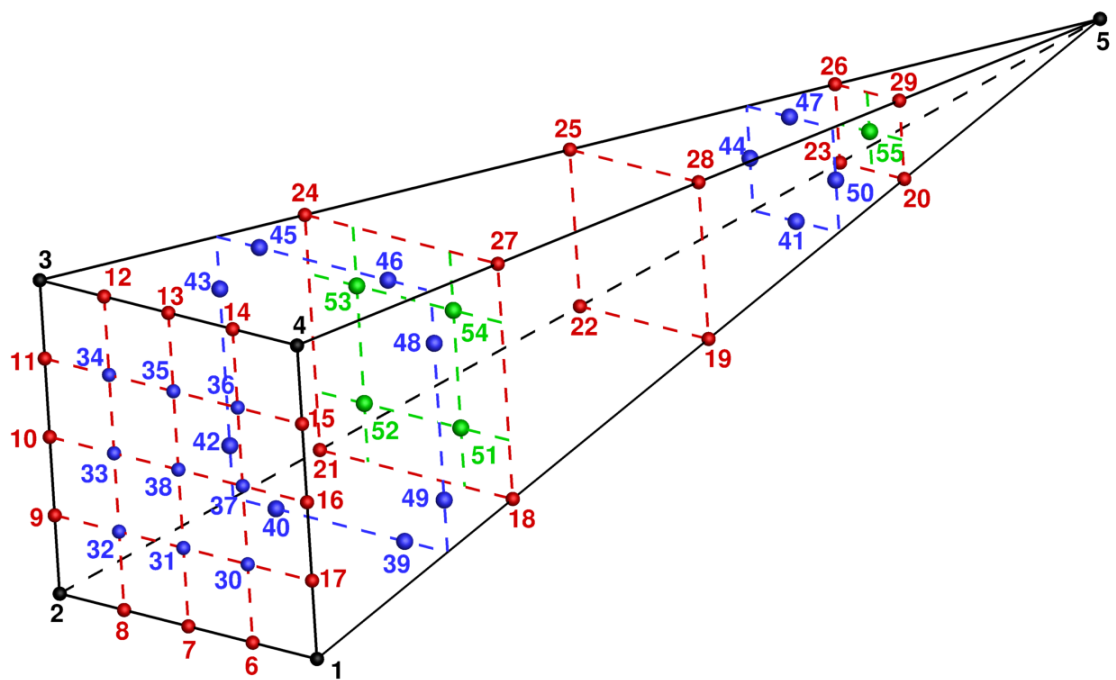
Oriented edges	Corner nodes	Mid-nodes
E1	N1,N2	N6,N7,N8
E2	N2,N3	N9,N10,N11
E3	N3,N4	N12,N13,N14
E4	N4,N1	N15,N16,N17
E5	N1,N5	N18,N19,N20
E6	N2,N5	N21,N22,N23
E7	N3,N5	N24,N25,N26
E8	N4,N5	N27,N28,N29

Face Definition

Oriented edges	Corner nodes	Mid-edge nodes	Oriented edges
F1	N1,N4,N3,N2	N17,N16,N15,N14,N13,N12, N11,N10,N9,N8,N7,N6	-E4,-E3,-E2,-E1
F2	N1,N2,N5	N6,N7,N8,N21,N22,N23, N20,N19,N18	E1,E6,-E5
F3	N2,N3,N5	N9,N10,N11,N24,N25,N26, N23,N22,N21	E2,E7,-E6
F4	N3,N4,N5	N12,N13,N14,N27,N28,N29, N26,N25,N24	E3,E8,-E7
F5	N4,N1,N5	N15,N16,N17,N18,N19,N20, N29,N28,N27	E4,E5,-E8



PYRA_50



PYRA_55

Location of mid-face nodes on triangular surfaces

N39 is located at the centroid of sub-triangle N1-N7-N19; N40 is located at the centroid of sub-triangle N2-N22-N7; N41 is located at the centroid of sub-triangle N5-N19-N22; N42 is located at the centroid of sub-triangle N2-N10-N22; N43 is located at the centroid of sub-triangle N3-N25-N10; N44 is located at the centroid of sub-triangle N5-N22-N25; N45 is located at the centroid of sub-triangle N3-N13-N25; N46 is located at the centroid of sub-triangle N4-N28-N13; N47 is located at the centroid of sub-triangle N5-N25-N28; N48 is located at the centroid of sub-triangle N4-N16-N28; N49 is located at the centroid of sub-triangle N1-N19-N16; N50 is located at the centroid of sub-triangle N5-N28-N19.

Location of volume nodes

N51 is the intersection of the line N5-N30 and the face N18-N21-N24-N27; N52 is the intersection of the line N5-N32 and the face N18-N21-N24-N27; N53 is the intersection of the line N5-N34 and the face N18-N21-N24-N27; N54 is the intersection of the line N5-N36 and the face N18-N21-N24-N27; N55 is the intersection of the line N5-N38 and the face N20-N23-N26-N29.

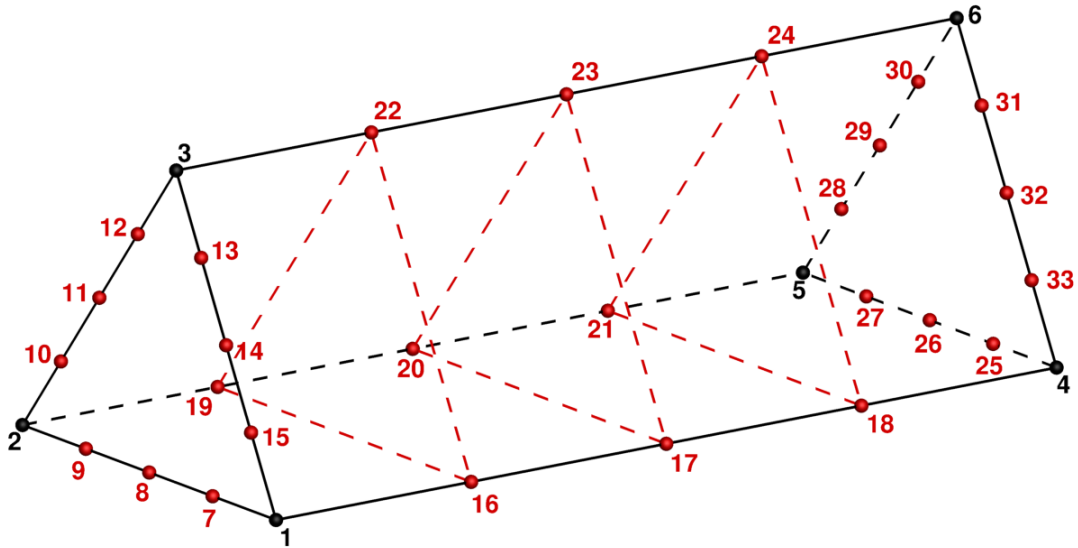
Edge Definition

Oriented edges	Corner nodes	Mid-nodes
E1	N1,N2	N6,N7,N8
E2	N2,N3	N9,N10,N11
E3	N3,N4	N12,N13,N14
E4	N4,N1	N15,N16,N17
E5	N1,N5	N18,N19,N20
E6	N2,N5	N21,N22,N23
E7	N3,N5	N24,N25,N26
E8	N4,N5	N27,N28,N29

Face Definition

Oriented edges	Corner nodes	Mid-edge nodes	Mid-face nodes	Oriented edges
F1	N1,N4,N3,N2	N17,N16,N15,N14,N13,N12, N11,N10,N9,N8,N7,N6	N30,N31,N32, N33,N34,N35, N36,N37,N38	-E4,-E3,-E2,-E1
F2	N1,N2,N5	N6,N7,N8,N21,N22,N23, N20,N19,N18	N39,N40,N41	E1,E6,-E5
F3	N2,N3,N5	N9,N10,N11,N24,N25,N26, N23,N22,N21	N42,N43,N44	E2,E7,-E6
F4	N3,N4,N5	N12,N13,N14,N27,N28,N29, N26,N25,N24	N45,N46,N47	E3,E8,-E7
F5	N4,N1,N5	N15,N16,N17,N18,N19,N20, N29,N28,N27	N48,N49,N50	E4,E5,-E8

3.3 Pentahedral Element



PENTA_33

Edge Definition

Oriented edges	Corner nodes	Mid-nodes
E1	N1,N2	N7,N8,N9
E2	N2,N3	N10,N11,N12
E3	N3,N1	N13,N14,N15
E4	N1,N4	N16,N17,N18
E5	N2,N5	N19,N20,N21
E6	N3,N6	N22,N23,N24
E7	N4,N5	N25,N26,N27
E8	N5,N6	N28,N29,N30
E9	N6,N4	N31,N32,N33

Face Definition

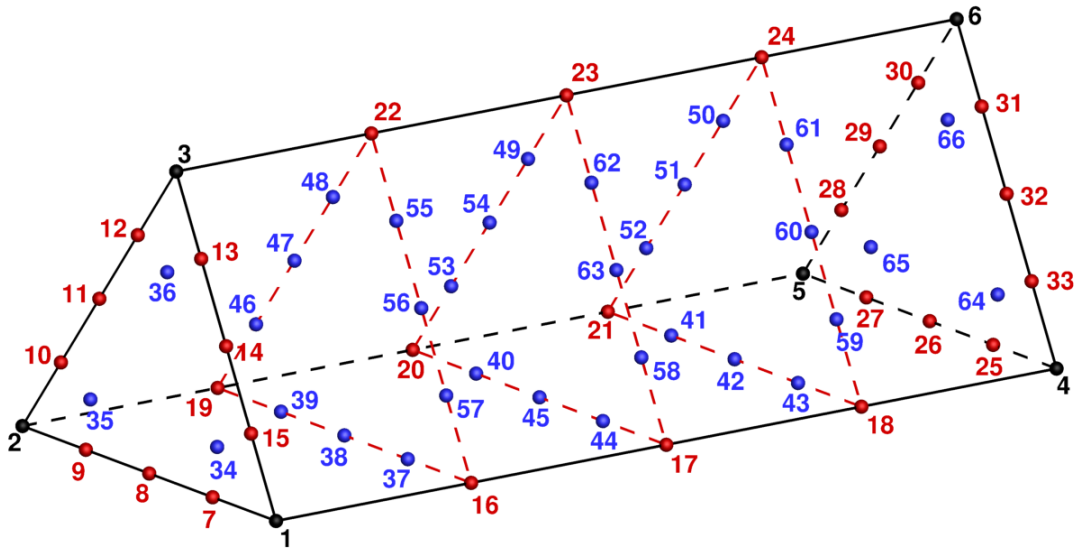
Oriented edges	Corner nodes	Mid-edge nodes	Oriented edges
F1	N1,N2,N5,N4	N7,N8,N9,N19,N20,N21, N27,N26,N25,N18,N17,N16	E1,E5,-E7,-E4
F2	N2,N3,N6,N5	N10,N11,N12,N22,N23,N24, N30,N29,N28,N21,N20,N19	E2,E6,-E8,-E5
F3	N3,N1,N4,N6	N13,N14,N15,N16,N17,N18, N33,N32,N31,N24,N23,N22	E3,E4,-E9,-E6
F4	N1,N3,N2	N15,N14,N13,N12,N11,N10, N9,N8,N7	-E3,-E2,-E1

F5

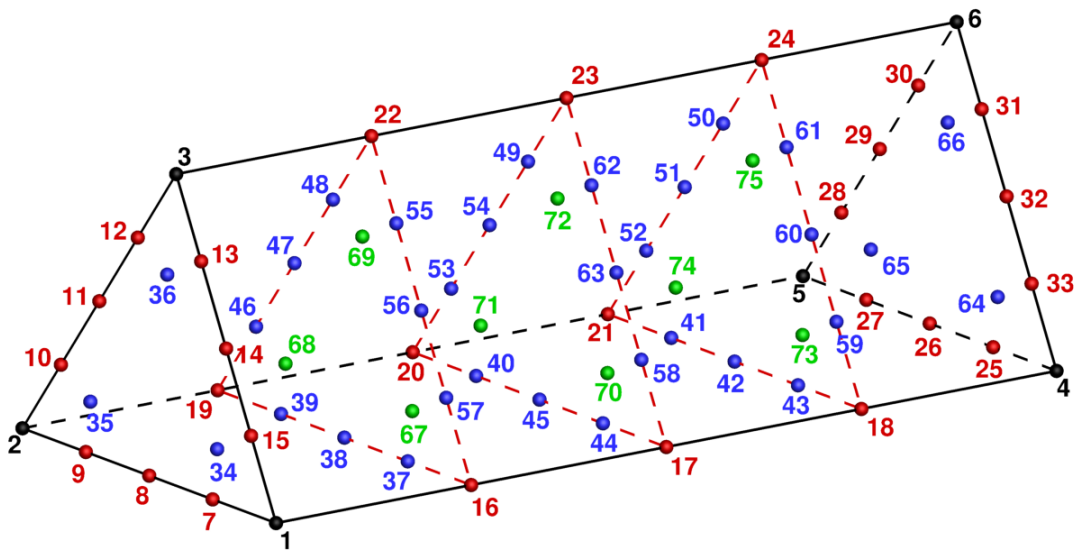
N4,N5,N6

N25,N26,N27,N28,N29,N30,
N31,N32,N33

E7,E8,E9



PENTA_66



PENTA_75

Location of mid-face nodes on triangular surfaces

N34 is located at the centroid of sub-triangle N1-N14-N8; N35 is located at the centroid of sub-triangle N2-N8-N11; N36 is located at the centroid of sub-triangle N3-N11-N14; N64 is located at the centroid of sub-triangle N4-N26-N32; N65 is located at the centroid of sub-triangle N5-N29-N26; N66 is located at the centroid of sub-triangle N6-N32-N29.

Location of volume nodes

N67 is located at the centroid of sub-triangle N16-N38-N56; N68 is located at the centroid of sub-triangle N19-N47-N38; N69 is located at the centroid of sub-triangle N22-N56-N47; N70 is located at the centroid of sub-triangle N17-N45-N63; N71 is located at the centroid of sub-triangle N20-N54-N45; N72 is located at the centroid of sub-triangle N23-N63-N54; N73 is located at the centroid of sub-triangle N18-N42-N60; N74 is located at the centroid of sub-triangle N21-N51-N42; N75 is located at the centroid of sub-triangle N24-N60-N51.

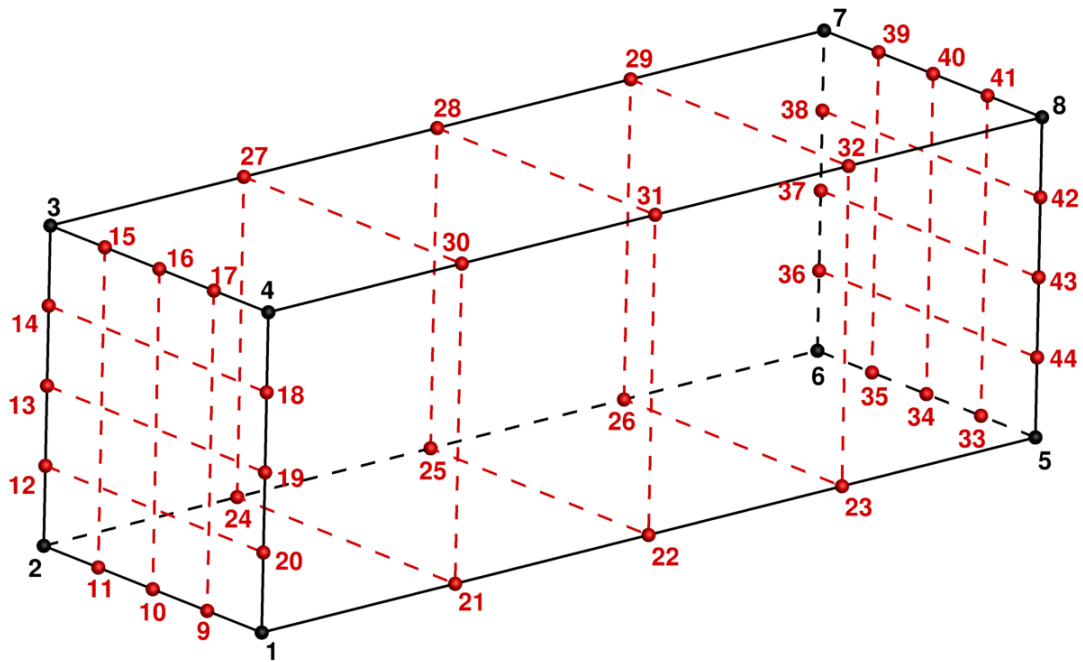
Edge Definition

Oriented edges	Corner nodes	Mid-nodes
E1	N1,N2	N7,N8,N9
E2	N2,N3	N10,N11,N12
E3	N3,N1	N13,N14,N15
E4	N1,N4	N16,N17,N18
E5	N2,N5	N19,N20,N21
E6	N3,N6	N22,N23,N24
E7	N4,N5	N25,N26,N27
E8	N5,N6	N28,N29,N30
E9	N6,N4	N31,N32,N33

Face Definition

Oriented edges	Corner nodes	Mid-edge nodes	Mid-face nodes	Oriented edges
F1	N1,N2,N5,N4	N7,N8,N9,N19,N20,N21, N27,N26,N25,N18,N17,N16	N37,N38,N39, N40,N41,N42, N43,N44,N45	E1,E5,-E7,-E4
F2	N2,N3,N6,N5	N10,N11,N12,N22,N23,N24, N30,N29,N28,N21,N20,N19	N46,N47,N48, N49,N50,N51, N52,N53,N54	E2,E6,-E8,-E5
F3	N3,N1,N4,N6	N13,N14,N15,N16,N17,N18, N33,N32,N31,N24,N23,N22	N55,N56,N57, N58,N59,N60, N61,N62,N63	E3,E4,-E9,-E6
F4	N1,N3,N2	N15,N14,N13,N12,N11,N10, N9,N8,N7	N34,N35,N36	-E3,-E2,-E1
F5	N4,N5,N6	N25,N26,N27,N28,N29,N30, N31,N32,N33	N64,N65,N66	E7,E8,E9

3.4 Hexahedral Element



HEXA_44

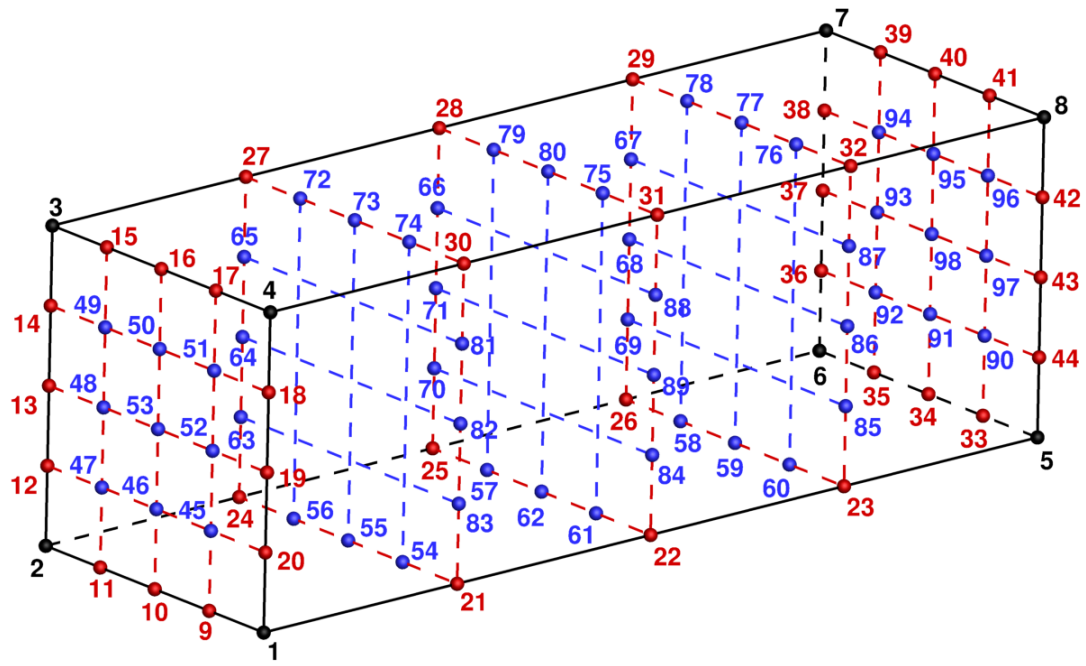
Edge Definition

Oriented edges	Corner nodes	Mid-nodes
E1	N1,N2	N9,N10,N11
E2	N2,N3	N12,N13,N14
E3	N3,N4	N15,N16,N17
E4	N4,N1	N18,N19,N20
E5	N1,N5	N21,N22,N23
E6	N2,N6	N24,N25,N26
E7	N3,N7	N27,N28,N29
E8	N4,N8	N30,N31,N32
E9	N5,N6	N33,N34,N35
E10	N6,N7	N36,N37,N38
E11	N7,N8	N39,N40,N41
E12	N8,N5	N42,N43,N44

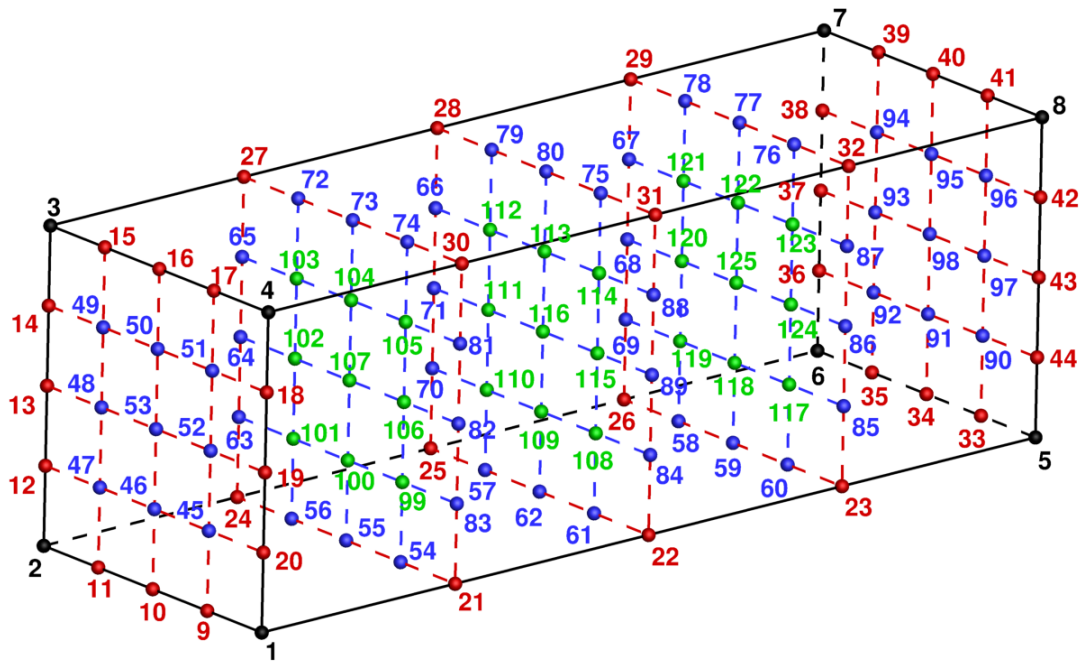
Face Definition

Oriented edges	Corner nodes	Mid-edge nodes	Oriented edges
F1	N1,N4,N3,N2	N20,N19,N18,N17,N16,N15, N14,N13,N12,N11,N10,N9	-E4,-E3,-E2,-E1
F2	N1,N2,N6,N5	N9,N10,N11,N24,N25,N26, N35,N34,N33,N23,N22,N21	E1,E6,-E9,-E5
F3	N2,N3,N7,N6	N12,N13,N14,N27,N28,N29, N38,N37,N36,N26,N25,N24	E2,E7,-E10,-E6
F4	N3,N4,N8,N7	N15,N16,N17,N30,N31,N32,	E3,E8,-E11,-E7

F5	N1,N5,N8,N4	N41,N40,N39,N29,N28,N27 N21,N22,N23,N44,N43,N42, N32,N31,N30,N18,N19,N20	E5,-E12,-E8,E4
F6	N5,N6,N7,N8	N33,N34,N35,N36,N37,N38, N39,N40,N41,N42,N43,N44	E9,E10,E11,E12



HEXA_98



HEXA_125

Edge Definition

Oriented edges	Corner nodes	Mid-nodes
E1	N1,N2	N9,N10,N11
E2	N2,N3	N12,N13,N14
E3	N3,N4	N15,N16,N17
E4	N4,N1	N18,N19,N20
E5	N1,N5	N21,N22,N23
E6	N2,N6	N24,N25,N26
E7	N3,N7	N27,N28,N29
E8	N4,N8	N30,N31,N32
E9	N5,N6	N33,N34,N35
E10	N6,N7	N36,N37,N38
E11	N7,N8	N39,N40,N41
E12	N8,N5	N42,N43,N44

Face Definition

Oriented edges	Corner nodes	Mid-edge nodes	Mid-face nodes	Oriented edges
F1	N1,N4,N3,N2	N20,N19,N18,N17,N16,N15, N14,N13,N12,N11,N10,N9	N45,N46,N47, N48,N49,N50, N51,N52,N53	-E4,-E3,-E2,-E1
F2	N1,N2,N6,N5	N9,N10,N11,N24,N25,N26, N35,N34,N33,N23,N22,N21	N54,N55,N56, N57,N58,N59, N60,N61,N62	E1,E6,-E9,-E5
F3	N2,N3,N7,N6	N12,N13,N14,N27,N28,N29,	N63,N64,N65,	E2,E7,-E10,-E6

		N38,N37,N36,N26,N25,N24	N66,N67,N68, N69,N70,N71	
F4	N3,N4,N8,N7	N15,N16,N17,N30,N31,N32, N41,N40,N39,N29,N28,N27	N72,N73,N74, N75,N76,N77, N78,N79,N80	E3,E8,-E11,-E7
F5	N1,N5,N8,N4	N21,N22,N23,N44,N43,N42, N32,N31,N30,N18,N19,N20	N81,N82,N83, N84,N85,N86, N87,N88,N89	E5,-E12,-E8,E4
F6	N5,N6,N7,N8	N33,N34,N35,N36,N37,N38, N39,N40,N41,N42,N43,N44	N90,N91,N92, N93,N94,N95, N96,N97,N98	E9,E10,E11,E12