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Tightly-attached Semi-transitive Graphs

Abstract:

This paper will outline methods devised to find tightly-attached semi-transitive orientations for undirected graphs.

Introduction:

A simple definition of semi-transitive is the following: a graph is semi-transitive provided that there exists an orientation of the graph so that symmetries of that orientation make all the vertices alike and all the edges alike. A symmetry of a graph is an element of the set of permutations of the vertices which preserves edges. This is also called an automorphism. The group of symmetries of a graph are referred to as the automorphism group. It now suffices to define transitive. G is transitive on X if $\forall x, y \in X \exists g \in G \ni y = xg$. A graph is vertex transitive provided that the automorphism group of the graph is transitive on vertices. The definitions of

edge and dart transitive are similar. An alternant of an oriented graph is found by taking one edge and including all of the edges that meet with a tail at its tail. Then all of the edges are included that meet with a head at the heads of all of those edges, and then those that meet with tails at their tails, etc. The set of vertices at the heads of the edges of each alternant is called a head set. The head sets partition the vertex set. The vertices can also be partitioned by tail sets.

Semi-transitive graphs:

"Given a semi-transitive graph, find a semi-transitive orientation for that graph." "How many non-isomorphic orientations can a semi-transitive graph have?" These problems are both without concrete answers. In an attempt to answer these questions, let us consider the following example.

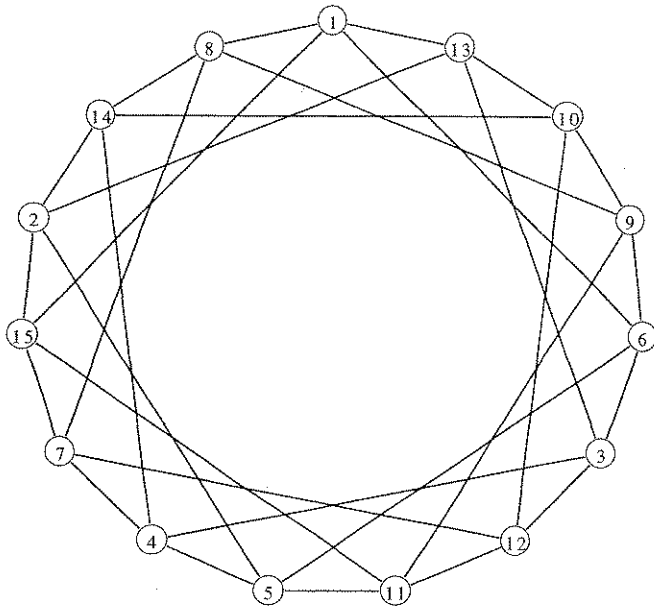


Figure A: $C_{15}(1,4)$

Now, this graph does have a finite number of edges, 30, and each edge can be directed only one of two ways, so the number of orientations for this graph is finite, though large, 2^{30} . It would be possible to check every orientation to see if it is semi-transitive. This is not practical. Perhaps another method of finding semi-transitive orientations would be beneficial.

Tightly-attached orientations:

A tightly-attached orientation is an orientation in which every head set is also a tail set for another

alternet. A graph with a tightly attached orientation could be arranged to look like the graph in Appendix A. All tightly-attached orientations are semi-transitive. So, by finding tightly-attached orientations for graphs, we have found semi-transitive orientations for those graphs.

Method 1 - Inspecting the Group:

One possible way of finding a tightly-attached orientation is by inspecting the group of the graph. Consider the following example.

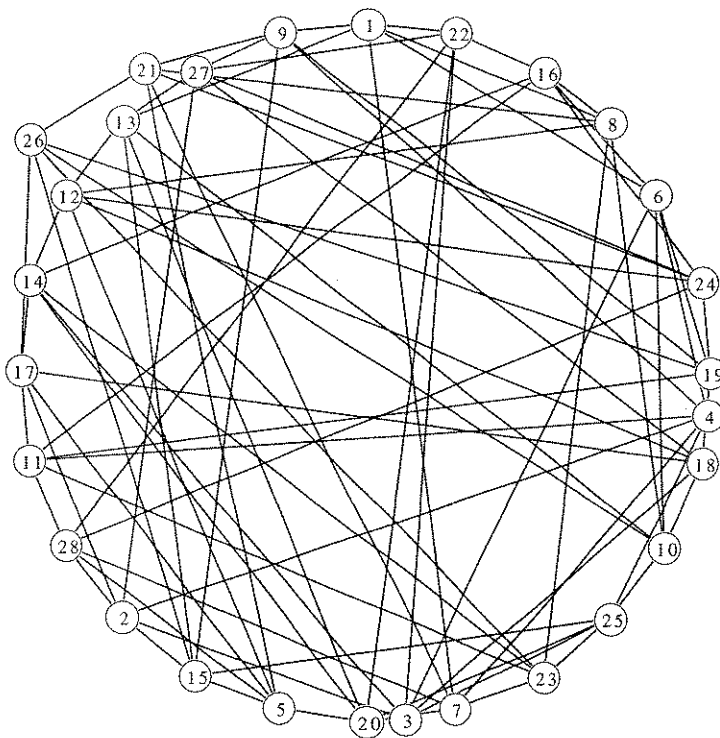


Figure B: 28 Vertices, 84 Edges

Now, we can inspect the group elements to find a permutation that moves all of the vertices. This permutation will need to have cycles of a size that divides the size of the vertex set. When we find a permutation as such, we will put the vertices in groups according to those cycles around a circle and orient the edges clockwise. See Appendix B for the group of the above graph. The permutation denoted with a $*$ will be used to arrange the vertices. An organization according to this permutation can be found in Appendix C. An oriented graph of that organization can be found in Appendix D. We can then check to see if the oriented graph is vertex and edge transitive. Proof of this can be found in Appendix E. Then, using the Orbit Stabilizer Theorem, we can take some element of the vertex set, a , and see if the out-neighbors of a are in the same orbit under a . The stabilizer of 1 can be found in Appendix F. If so, we have found a semi-transitive orientation for the graph. This method, though useful, is not completely efficient because one could spend a great deal of time trying several permutations that do not provide semi-transitive orientations.

Method 2 - Block System:

A block is defined in Permutation Groups by John D. Dixon and Brian Mortimer as the following: Let G be a group acting transitively on a set Ω . A nonempty subset Δ of Ω is called a block for G if for each $x \in G$ either $\Delta^x = \Delta$ or $\Delta^x \cap \Delta = \emptyset$. Consider the following example.

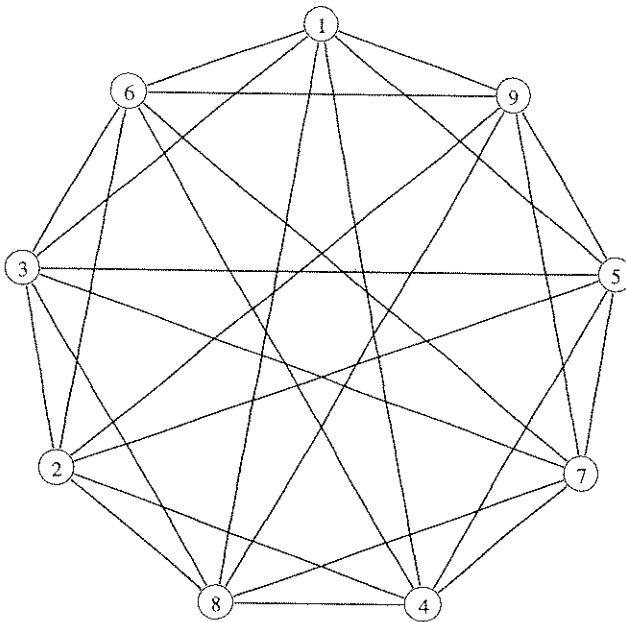


Figure C: $C_9(1,2,4)$

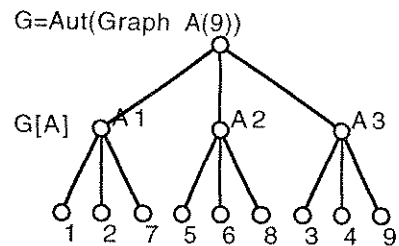


Figure D: Block for Figure C

So, we will arrange the vertices in groups according to a set of nontrivial blocks around a circle and orient the edges clockwise. See Appendix A for this orientation. We will again check to see if the oriented graph is vertex and edge transitive. We will then use the Orbit Stabilizer Theorem to see if the out-neighbors of a certain element are in the same orbit under that element. If so, the directed graph is semi-transitive. See Appendix G for the group of the orientation. See Appendix H for the stabilizer of vertex 1. This is a good method, but it does not work all of the time. The set Ω must be imprimitive, that is to say, not primitive. If Ω has no nontrivial blocks then it is said to be primitive. Trivial blocks are the set Ω and the singletons $\{\alpha\}$ ($\alpha \in \Omega$). An example of a primitive graph follows in Figure D.

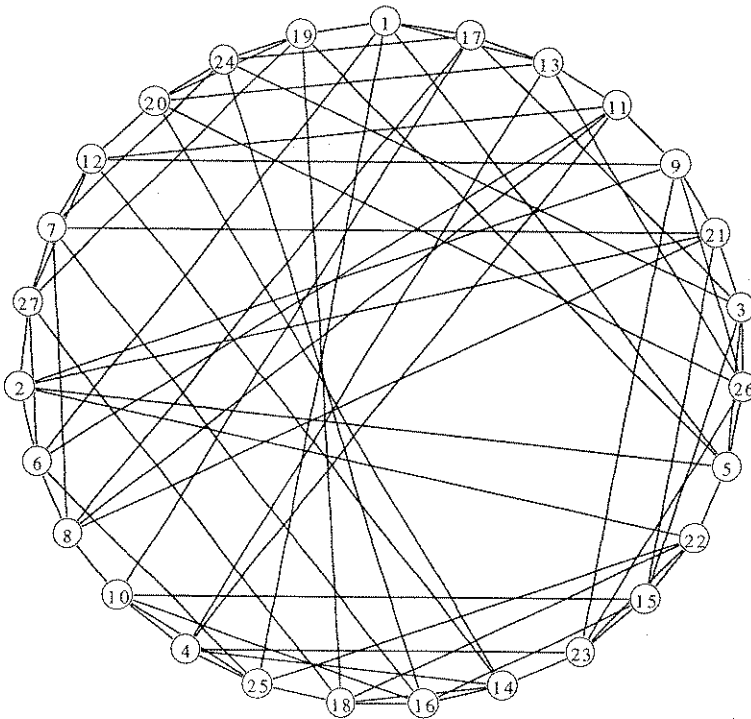


Figure D: An example of a primitive graph.

Also, even if a set Ω is imprimitive, its block system might not provide a tightly-attached orientation.

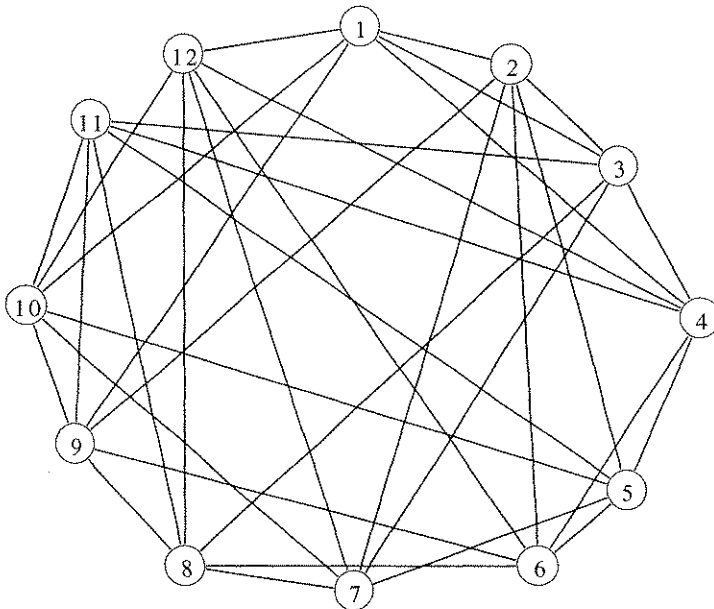


Figure E: An imprimitive graph

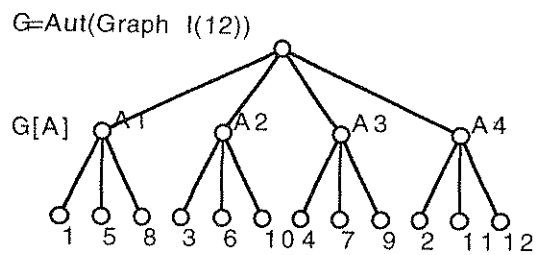
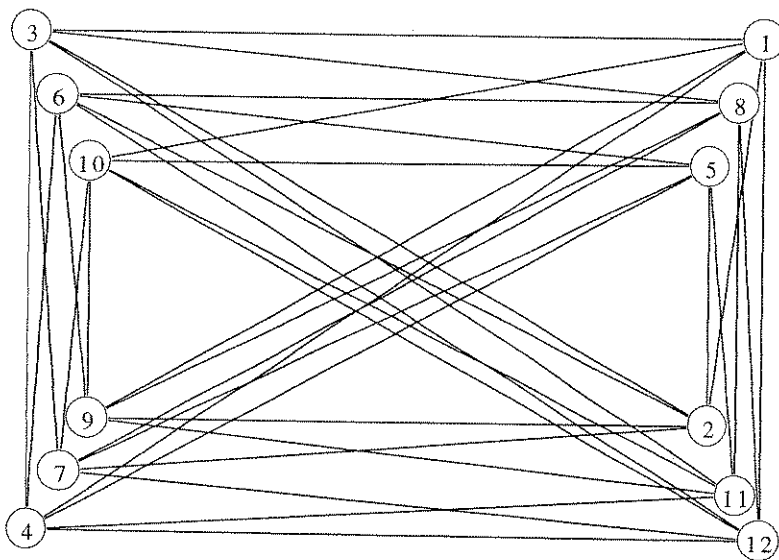


Figure F: Block for Figure E

Now, if we arrange the vertices according to the block above, we do not get a tightly attached orientation. This graph might be semi-transitive, but we cannot conclude that from the orientation that we have found.



Addressing Scheme:

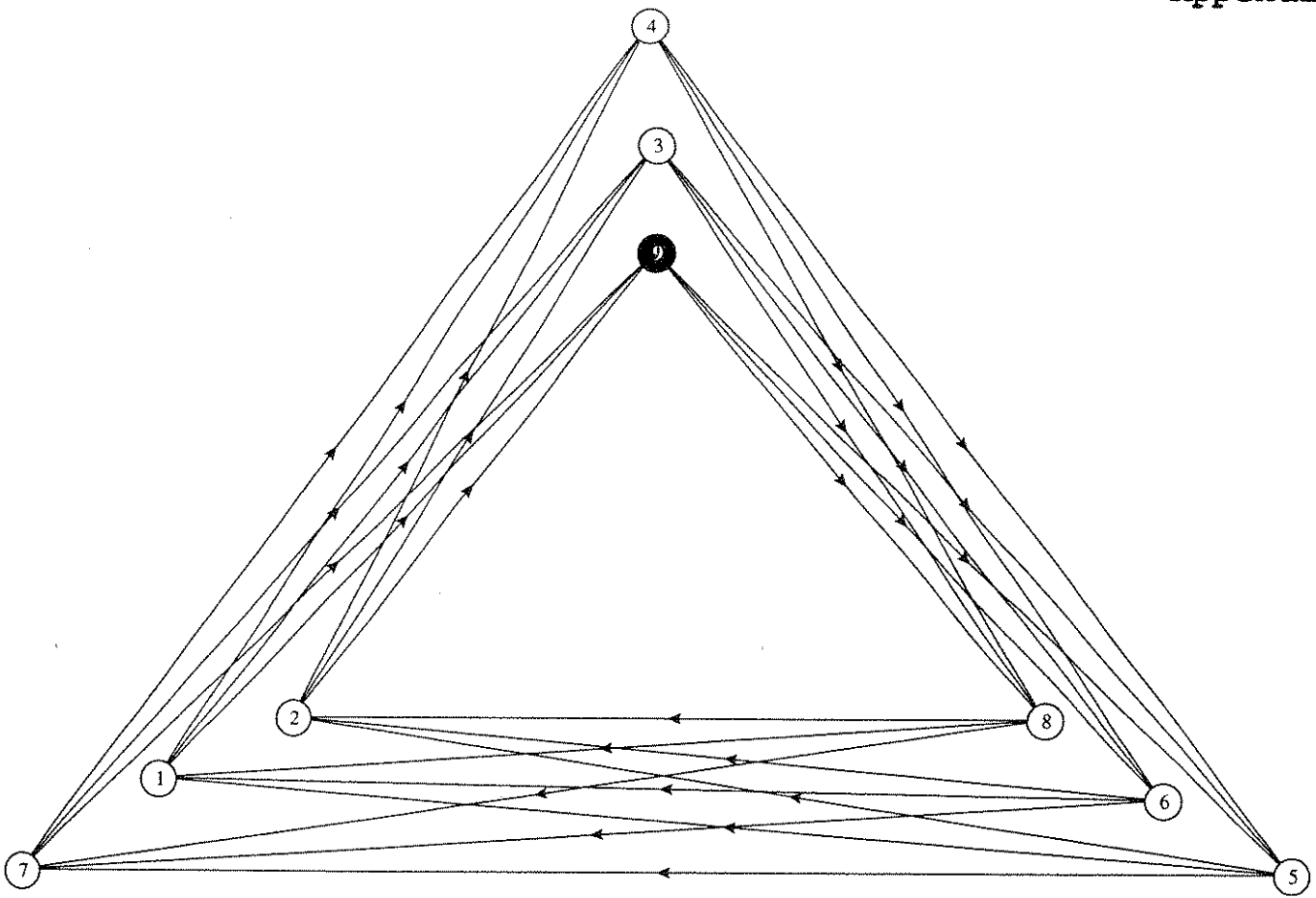
Take an oriented graph with at least two alternets that is worthy, that is to say, no two distinct vertices have the same neighbor set. Let the head sets be levels. Call the levels $L_0, L_1, L_2, \dots, L_{k-1}$. Let $L_k = L_0$. Call the vertices within L_i the following: $(i,1), (i,2), \dots, (i,N)$. Assign labels to $L_0, L_1, L_2, \dots, L_{k-1}$ by saying $(i,j)\lambda = (i+1,j)$ for $i=0,1,\dots,k-2$. Let $(k-1,j)\lambda = (0,j\sigma)$ for some $\sigma \in S_N$. Let $T = \{\mu \in \text{Aut}(\Delta) \mid L_0\mu = L_0\}$. For $\tau \in T$ let $(i,j)\tau = (i,j\tau_i)$ for $\tau_i \in S_N$. So, we are thinking of the permutations of the vertices as two different kinds of things, things that preserve levels and things that permute levels.

Method 3 - Possible Candidates for λ

Using the addressing scheme noted above, one can find all of the possible candidates for λ . The easiest way to find all possible candidates for λ is to rule out all elements of the group that could not be λ . So, eliminate from the list of group elements all permutations that do not include all of the vertices. The cycles within each permutation should be of a size that divides the size of the vertex set or of a size that is a multiple of something that divides the size of the vertex set. See the graph in Appendix I. Its list of group elements can be found in

Appendix J. Its list of possible candidates for λ can be found in Appendix K. Now, looking at Appendix K, take all of the things that map vertex 1 to some specific element. Let's pick 7. The idea is that each permutation is either a λ or a τ . If we assume 1 and 7 are in different levels then the two permutations that take 1 to 7 are λ s. So, looking at both of the permutations that send 1 to 7, lets arrange the vertices. This arrangement can be found in Appendix L. This orientation is tightly-attached. Another way of using candidates for λ is the following. Find all of the possible candidates for λ that will provide an x level orientation. Then makes some guesses about the permutations and try to arrange the vertices in that way. For example, consider the graph in Appendix M. The group for this graph can be found in Appendix N. Take all possible candidates for λ that are permutations made up of three cycles. These can be found in Appendix O. You will see in this list that the first three permutations are the inverses of the last three. So, using the first three permutations, arrange the vertices. A orientation of the graph according to these permutations can be found in Appendix P. As you can see, this is a tightly-attached orientation. One might think that using an inverse permutation in substitution for one of the previously used

permutations might provide a new tightly-attached orientation. Using the inverse of the first permutation instead of the first permutation gives the graph found in Appendix Q. Using the inverse of the second gives the graph in Appendix R. Using the inverse of the third gives the graph found in Appendix S. The graphs in Appendices P, Q, R, and S are isomorphic.



Digraph: Appendix A

9 Vertices, 27 Edges

Group: Appendix BDegree=28, Order=168 = $2^3 3^1 7^1$

non-abelian, 1-transitive

4 Generator(s):

a = (2,14,26)(3,23,15)(4,20,10)(5,18,11)(6,7,13)(8,9,22)(12,19,28)(16,21,27)

b = (2,5)(3,12)(4,21)(6,8)(7,9)(10,16)(11,26)(13,22)(14,18)(15,28)(19,23)(20,27)(24,25)

c = (1,21,23,10,15,20,12,17,3,27,28,16,19,4)(2,22,24,11,6,9,7,8,26,25,13,5,14,18)

d = (1,18,21,2,23,22,10,24,15,11,20,6,12,9,17,7,3,8,27,26,28,25,16,13,19,5,4,14)

1 Orbit(s):

Orb(4), length=28: 4, 25, 24, 22, 9, 8, 13, 7, 6, 11, 18, 5, 26, 14, 2, 17, 28, 19, 12, 15, 23, 3, 1, 27, 21, 16, 10, 20

List of elements

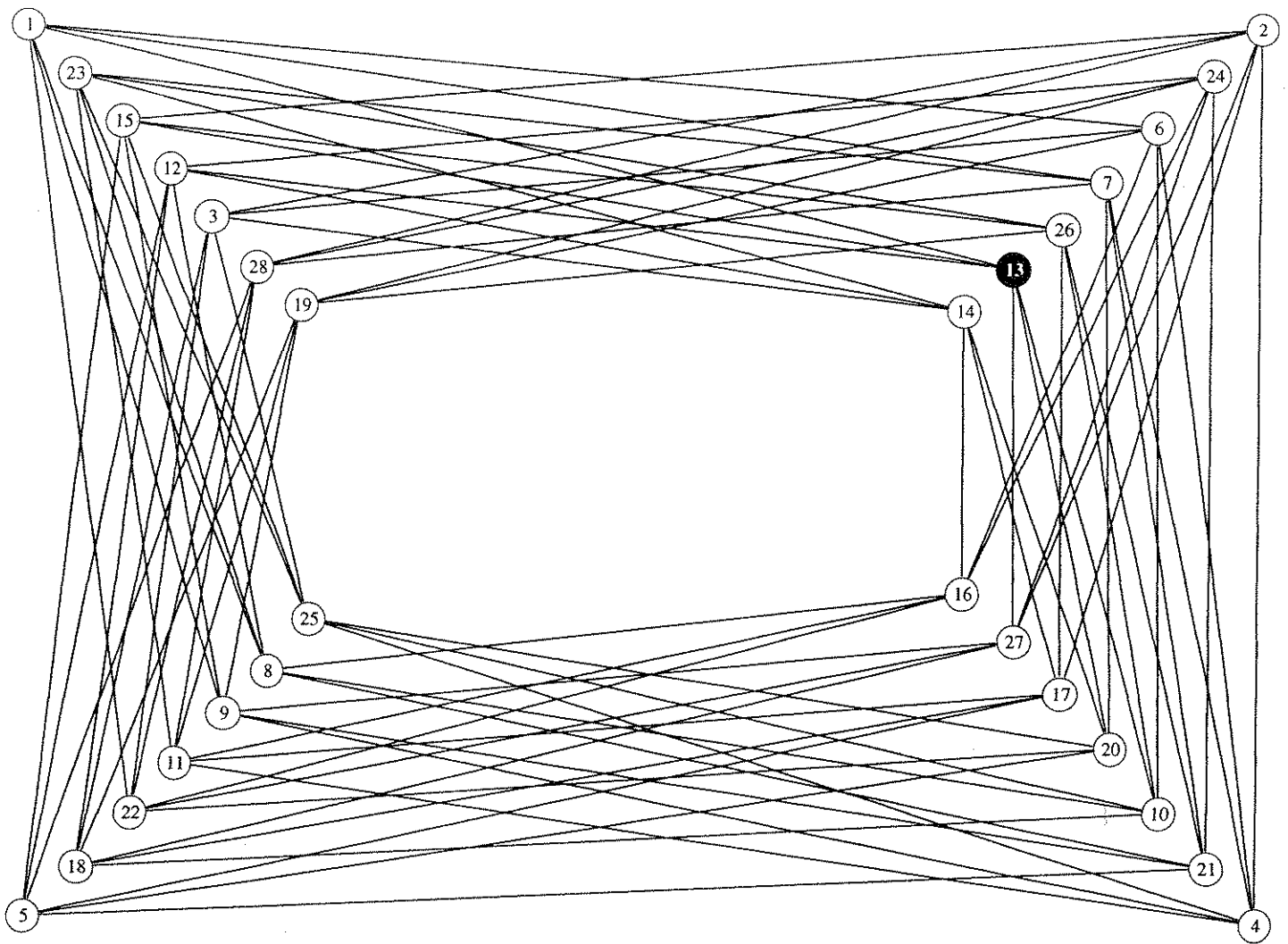
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 (1,26,27,25,12,6,17,22,23,24,4,5)(2,20,8,19)(3,14,16,11,28,7,21,9,15,13,10,18)
 (1,26,20,18,28,6,21,25,12,2,16,9,23,13,17,22,19,7,10,5,3,24,4,8,15,14,27,11)
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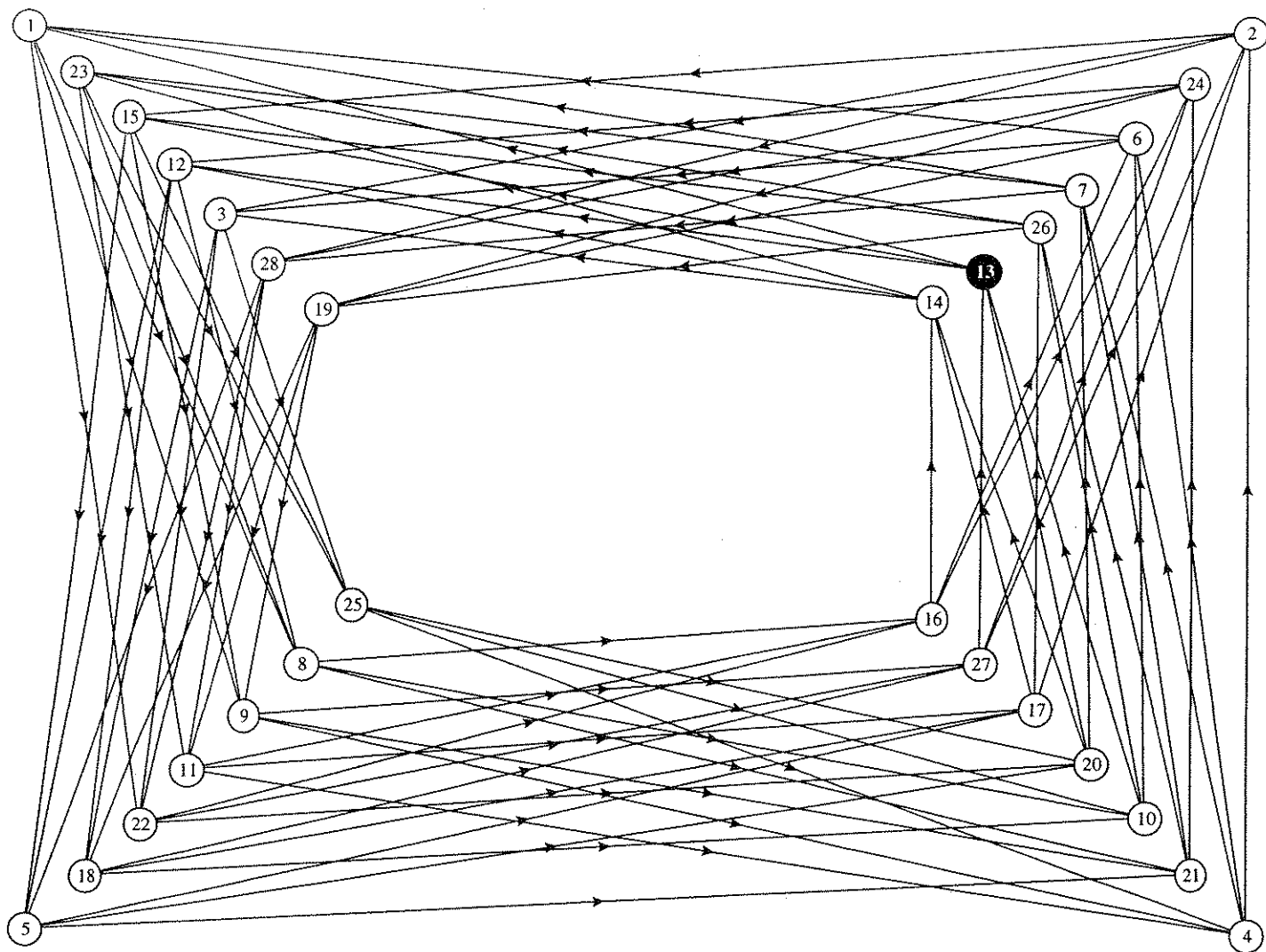
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(1,7,21,8,23,26,10,25,15,13,20,5,12,14,17,18,3,2,27,22,28,24,16,11,19,6,4,9)



Graph: Appendix C

28 Vertices, 84 Edges

Automorphism group has order 168



Digraph: Appendix D

28 Vertices, 84 Edges

Group: Appendix EDegree=28, Order=84 = $2^2 3 7$

non-abelian, 1-transitive

3 Generator(s):

a = (2,26,14)(3,15,23)(4,10,20)(5,11,18)(6,13,7)(8,22,9)(12,28,19)(16,27,21)

b = (1,27,28,17,23,10)(2,11,26,8,13,22)(3,4,19,21,12,20)(5,14,25,6,9,24)(7,18)(15,16)

c = (1,6,16,22,3,14,20,25,23,7,4,11,28,2,17,5,15,26,21,9,19,24,27,18,12,13,10,8)

1 Orbit(s):

Orb(3), length=28: 3, 25, 24, 18, 11, 5, 14, 26, 2, 9, 22, 8, 7, 13, 6, 17, 1, 21, 27, 16, 19, 28, 12, 20,
10, 4, 23, 15

Group: Appendix F

Degree=28, Order=3

abelian, intransitive

subgroup of Appendix E

1 Generator(s):

a = (2,26,14)(3,15,23)(4,10,20)(5,11,18)(6,13,7)(8,22,9)(12,28,19)(16,27,21)

12 Orbit(s):

Orb(1), length=1:	1
Orb(2), length=3:	2, 14, 26
Orb(3), length=3:	3, 23, 15
Orb(4), length=3:	4, 20, 10
Orb(5), length=3:	5, 18, 11
Orb(6), length=3:	6, 7, 13
Orb(8), length=3:	8, 9, 22
Orb(12), length=3:	12, 19, 28
Orb(16), length=3:	16, 21, 27
Orb(17), length=1:	17
Orb(24), length=1:	24
Orb(25), length=1:	25

Group: Appendix GDegree=9, Order=648 = $2^3 3^4$

non-abelian, 1-transitive

7 Generator(s):

a = (4,9)

b = (3,9,4)

c = (3,9,4)(6,8)

d = (3,9,4)(5,8,6)

e = (2,7)(3,9,4)(5,8,6)

f = (1,7,2)(3,9,4)(5,8,6)

g = (1,8,4,2,5,9,7,6,3)

1 Orbit(s):Orb(2), length=9: 2, 3, 9, 4, 5, 8, 6, 1, 7

Group: Appendix HDegree=9, Order=72 = $2^3 3^2$

non-abelian, intransitive

subgroup of Appendix G

5 Generator(s):

a = (4,9)

b = (3,9,4)

c = (3,9,4)(6,8)

d = (3,9,4)(5,8,6)

e = (2,7)(3,9,4)(5,8,6)

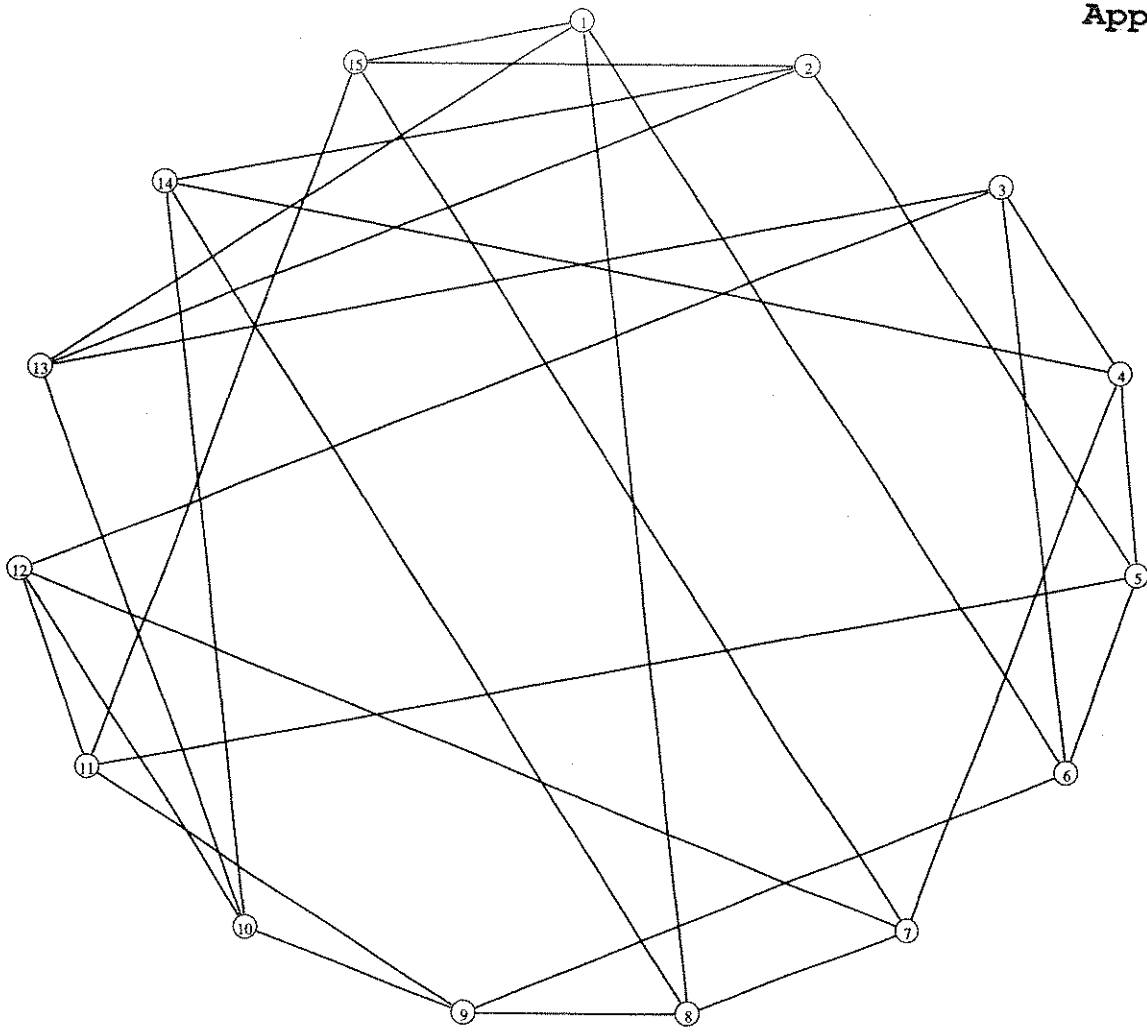
4 Orbit(s):

Orb(1), length=1: 1

Orb(2), length=2: 2, 7

Orb(4), length=3: 4, 3, 9

Orb(6), length=3: 6, 5, 8



Graph: Appendix I

15 Vertices, 30 Edges

Group: Appendix JDegree=15, Order=60 = $2^2 3^1 5^1$

non-abelian, intransitive

4 Generator(s):

a = (3,7)(5,14)(6,8)(10,11)(13,15)

b = (2,9)(4,12)(5,10)(6,13)(8,15)(11,14)

c = (1,9,12,4,2)(3,5,15,8,10)(6,11,7,14,13)

d = (1,5,12,8,2,3,9,15,4,10)(6,11,7,14,13)

1 Orbit(s):

Orb(5), length=15: 5, 12, 4, 1, 9, 2, 15, 13, 8, 6, 7, 3, 11, 10, 14

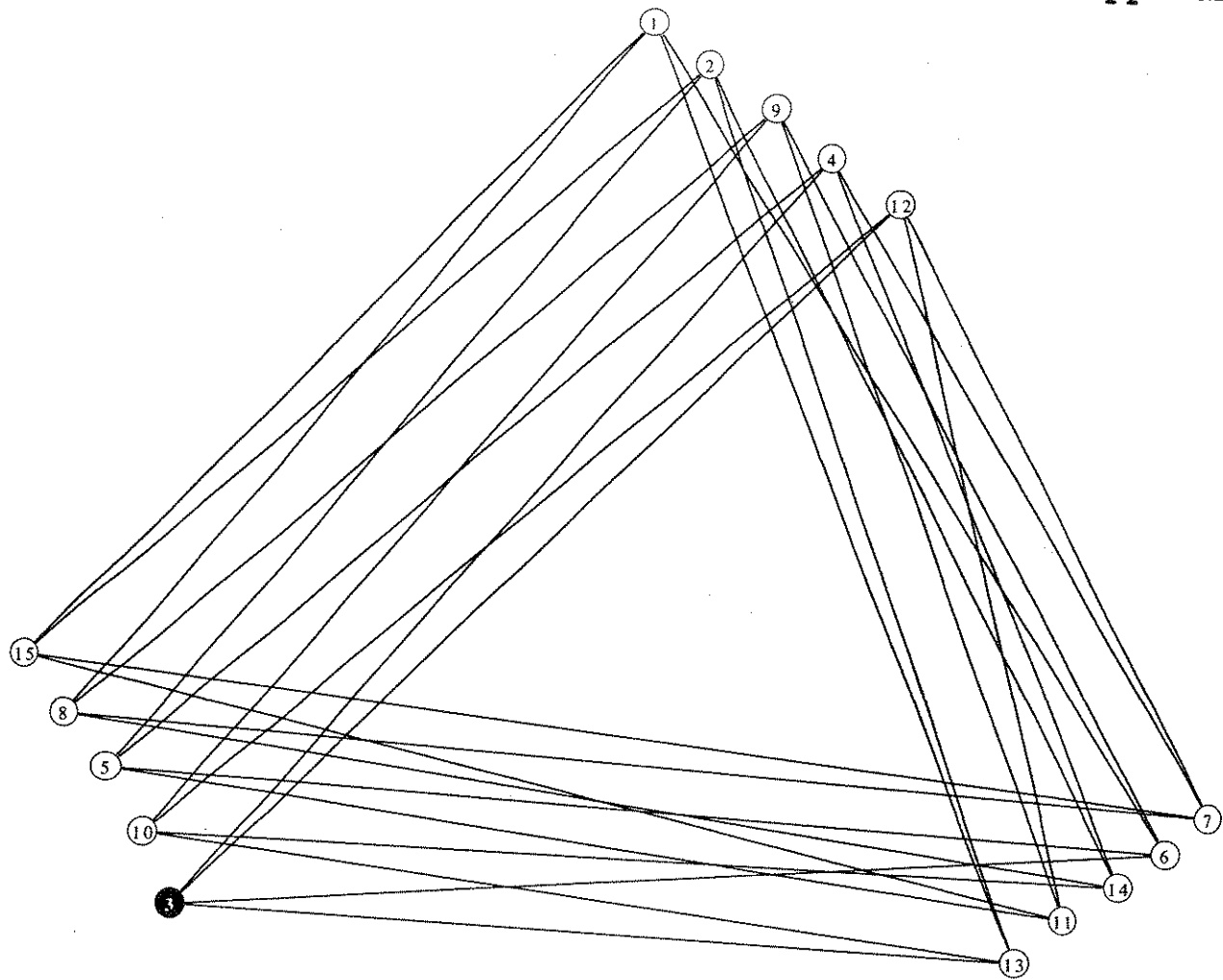
List of elements

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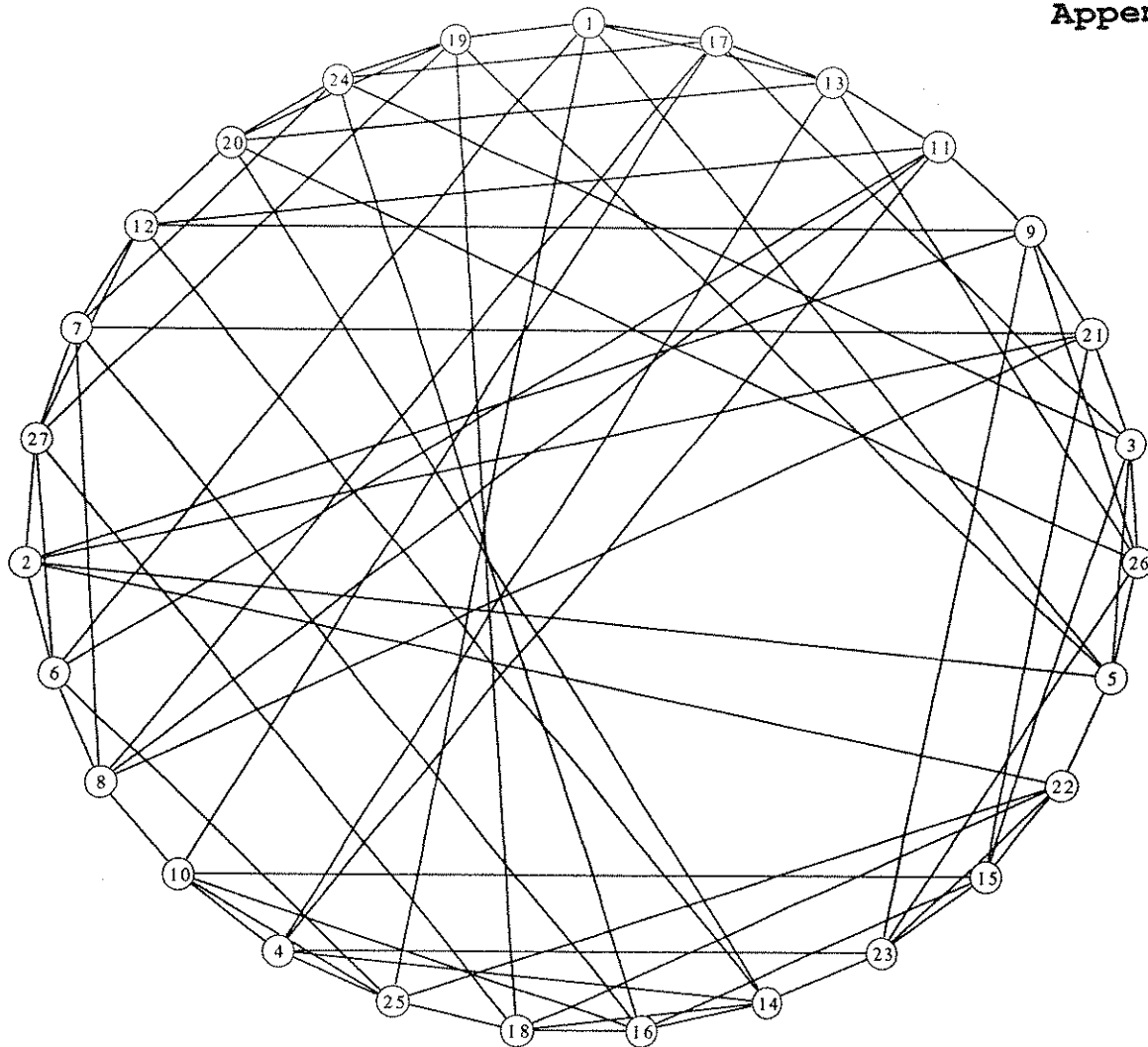
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 (1,15,7,12,3,13)(2,8,11,4,10,6)(5,14,9)
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 (1,4,9,2,12)(3,8,5,10,15)(6,14,11,13,7)
 (1,7)(2,14)(4,13)(5,10)(6,12)(8,15)(9,11)
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 (1,6)(2,11)(3,8)(4,7)(5,15)(9,13)(12,14)
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 (1,2,4,12,9)(3,10,8,15,5)(6,13,14,7,11)
 (1,14)(2,13)(3,5)(4,6)(7,9)(10,15)(11,12)
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(1,8,9,10,12,3,4,5,2,15)(6,14,11,13,7)
(1,7,3)(2,14,10,9,11,5)(4,13,8,12,6,15)
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(1,3,7)(2,10,11)(4,8,6)(5,14,9)(12,15,13)
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(1,3,7)(2,5,11,9,10,14)(4,15,6,12,8,13)
(1,8,14,2,15,7,4,5,11,12,3,6,9,10,13)
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(1,9,12,4,2)(3,14,15,6,10,7,5,13,8,11)
(1,5,13,4,10,7,9,15,6,2,3,14,12,8,11)
(1,8,7,4,3,6)(2,10,11)(5,13,9,15,14,12)
(1,2,4,12,9)(3,10,8,15,5)(6,13,14,7,11)
(1,11,4,13,9,7,2,6,12,14)(3,10,8,15,5)
(1,2,4,12,9)(3,11,8,13,5,7,10,6,15,14)
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(1,10,6,12,5,7,2,8,13,9,3,11,4,15,14)
(1,12,2,9,4)(3,15,10,5,8)(6,7,13,11,14)
(1,13,2,14,4,7,12,11,9,6)(3,15,10,5,8)
(1,12,2,9,4)(3,13,10,14,8,7,15,11,5,6)
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(1,5,12,8,2,3,9,15,4,10)(6,11,7,14,13)
(1,14,15,4,11,3,9,13,8,2,7,5,12,6,10)
(1,6,3,4,7,8)(2,11,10)(5,12,14,15,9,13)
(1,10,4,15,9,3,2,8,12,5)(6,13,14,7,11)
(1,14,3,9,7,5)(2,13,10,12,11,15)(4,6,8)
(1,11,8,12,14,3,2,6,15,9,7,10,4,13,5)
(1,15,2,5,4,3,12,10,9,8)(6,7,13,11,14)
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(1,11,3,2,7,10)(4,14,8,9,6,5)(12,13,15)
(1,13,3,12,7,15)(2,6,10,4,11,8)(5,9,14)
(1,7,3)(2,11,10)(4,6,8)(5,9,14)(12,13,15)
(1,7,3)(2,14,10,9,11,5)(4,13,8,12,6,15)
(1,6,5,2,13,3,4,14,10,12,7,8,9,11,15)



Graph: Appendix L
15 Vertices, 30 Edges



Graph: Appendix M

27 Vertices, 81 Edges

Group: Appendix N

Degree=27, Order=1296 = $2^4 3^4$

non-abelian, 1-transitive

5 Generator(s):

a = (3,8)(4,20)(5,6)(7,15)(10,24)(11,26)(12,23)(19,25)(22,27)

b = (3,26)(4,10)(7,12)(8,11)(9,21)(13,17)(14,16)(15,23)(20,24)

c = (2,18)(3,10)(4,26)(5,25)(6,19)(8,24)(9,14)(11,20)(16,21)

d = (2,10,20)(3,18,11)(4,26,22)(5,25,13)(6,17,19)(8,24,27)(9,15,14)(12,21,16)

e = (1,10,7,20,23,2)(3,18,11)(4,21,19)(5,25,8,24,14,9)(6,17,16,12,26,22)(13,15,27)

1 Orbit(s):

Orb(3), length=27: 3, 17, 13, 25, 19, 6, 5, 23, 12, 15, 7, 16, 14, 21, 9, 1, 27, 22, 18, 2, 24, 10, 20, 4, 26, 11, 8

List of elements

identity

(3,8)(4,20)(5,6)(7,15)(10,24)(11,26)(12,23)(19,25)(22,27)
 (3,26)(4,10)(7,12)(8,11)(9,21)(13,17)(14,16)(15,23)(20,24)
 (3,11)(4,24)(5,6)(7,23)(8,26)(9,21)(10,20)(12,15)(13,17)(14,16)(19,25)(22,27)
 (2,18)(3,10)(4,26)(5,25)(6,19)(8,24)(9,14)(11,20)(16,21)
 (2,18)(3,24)(4,11)(5,19)(6,25)(7,15)(8,10)(9,14)(12,23)(16,21)(20,26)(22,27)
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 (2,18)(3,20)(4,8)(5,19)(6,25)(7,23)(9,16)(10,11)(12,15)(13,17)(14,21)(22,27)(24,26)
 (2,10,20)(3,18,11)(4,26,22)(5,25,13)(6,17,19)(8,24,27)(9,15,14)(12,21,16)
 (2,10,27,4)(3,24,20,26)(5,17,19,13)(6,25)(7,14,9,15)(8,18,11,22)(12,23,21,16)
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 (2,10)(4,27)(5,17)(6,25)(7,23)(8,22)(9,16)(11,18)(12,14)(13,19)(15,21)(24,26)
 (2,11)(3,20)(4,22)(5,13)(8,27)(10,18)(12,21)(14,15)(17,19)
 (2,11,26)(3,27,4)(5,6,13)(7,14,15)(8,20,22)(10,24,18)(12,23,21)(17,19,25)
 (2,11,27,8)(3,26,20,24)(4,18,10,22)(5,13,19,17)(7,21,9,12)(14,16,15,23)
 (2,11,20,18,10,3)(4,24,22,8,26,27)(5,6,13,19,25,17)(7,23)(9,12,14,16,15,21)
 (2,24,22,20)(3,18,26,27)(4,11,8,10)(5,19)(6,17,25,13)(7,15,14,9)(12,21,16,23)
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 (2,24,11,18,26,10)(3,8,27,20,4,22)(5,17,6,19,13,25)(7,12,14,23,15,21)(9,16)
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 (2,3)(6,17)(9,15)(10,11)(12,16)(13,25)(18,20)(22,26)(24,27)
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 (2,20,22,24)(3,27,26,18)(4,10,8,11)(5,19)(6,13,25,17)(7,9,14,15)(12,23,16,21)
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 (1,21,19,15)(2,24,22,17)(3,5)(4,11,12,14)(6,7,18,10)(8,27,16,25)(9,20,23,13)
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 (1,21,13,7)(2,26,12,19)(3,11,24,6)(4,16,25,15)(5,9,20,27)(8,17)(14,18,22,23)
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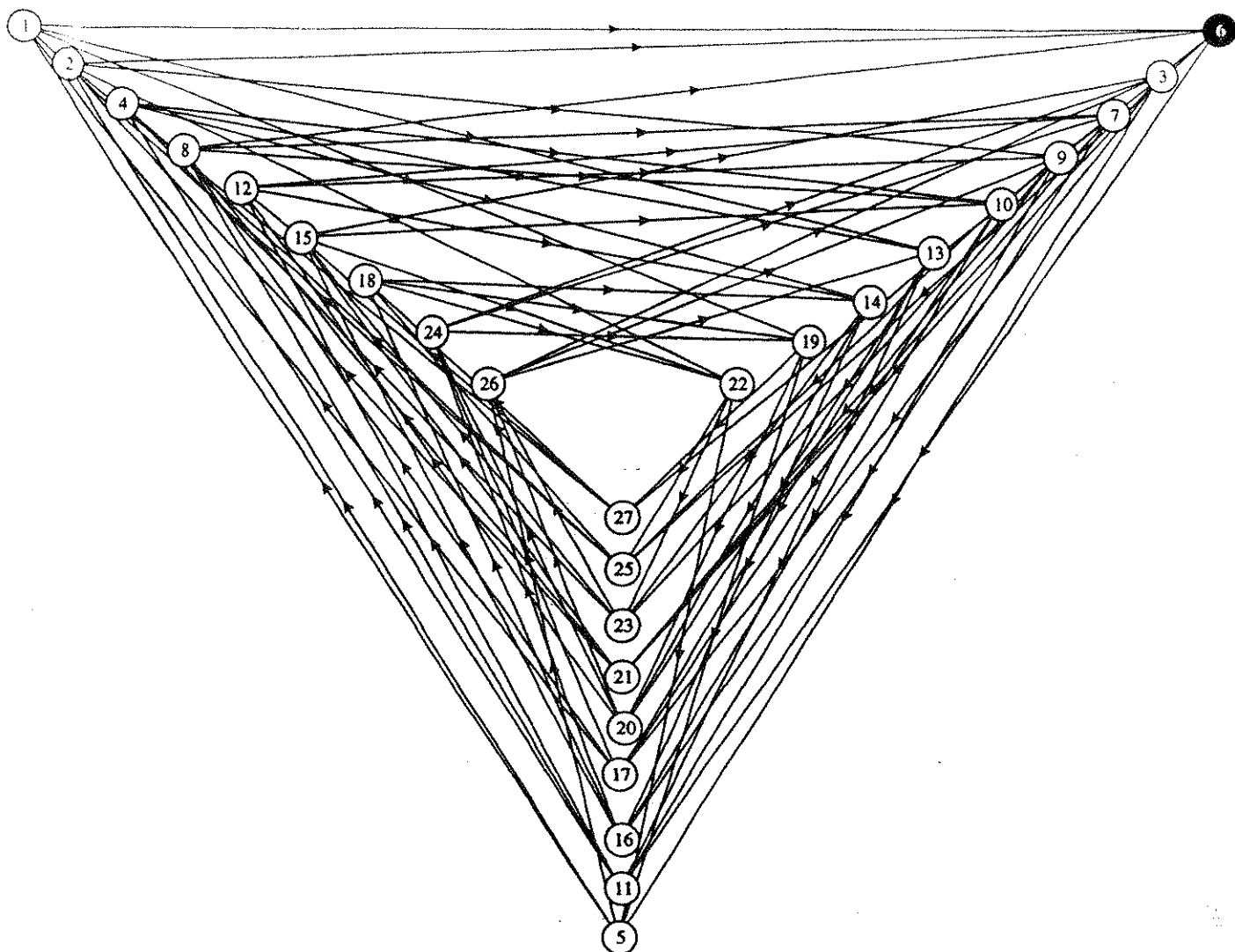
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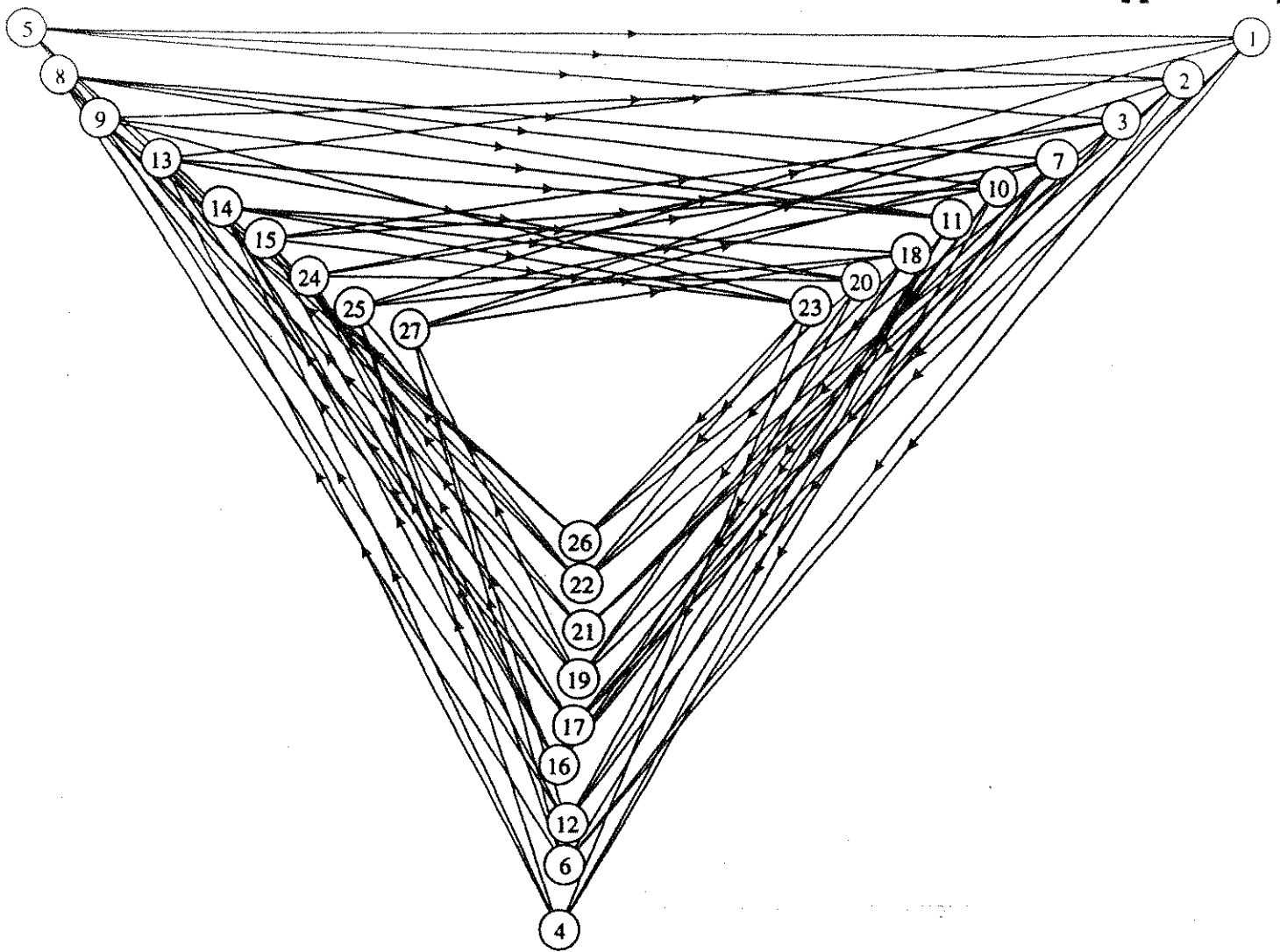
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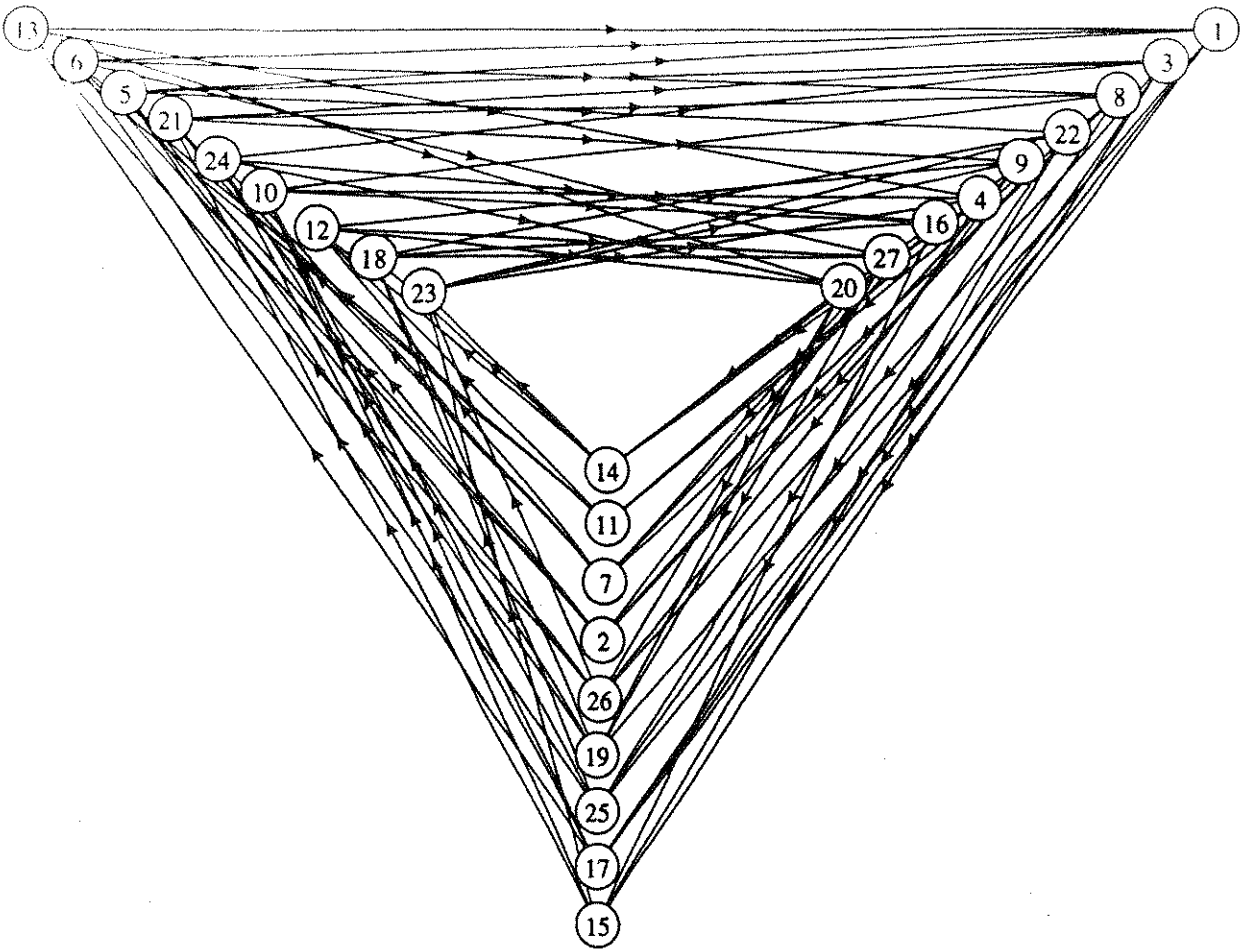
Digraph: Appendix P

27 Vertices, 81 Edges



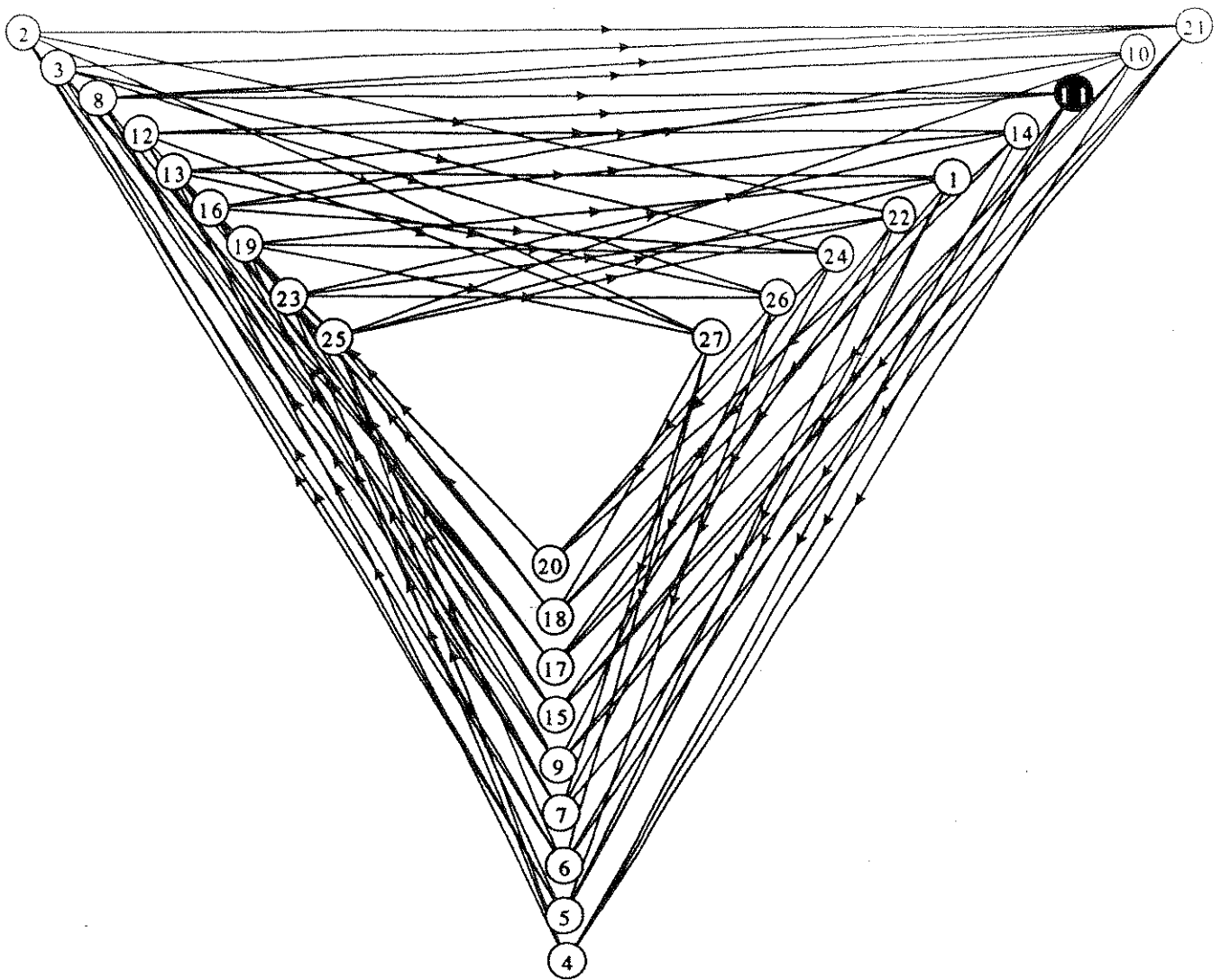
Digraph: Appendix Q

27 Vertices, 81 Edges



Digraph: Appendix R

27 Vertices, 81 Edges



Digraph: Appendix S

27 Vertices, 81 Edges