A Bibliography of Line Graphs of Signed Graphs, and Signed Graphs from Line Graphs

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A Adjacency matrix, eigenvalues.
Alg Algorithms.
Aut Automorphisms, symmetries, group actions.
B Balance (mathematical), cobalance.
Cl Clusterability.
Col Vertex coloring.
D Duality (graphs, matroids, or matrices).
E Enumeration of types of signed graphs, etc.
EC Even-cycle matroids.
ECol Edge coloring.
Exp Expository.
Exr Interesting exercises (in an expository work).
Fr Frustration index (line index of imbalance) and other measures of imbalance.
G Connections with geometry, including toric varieties, complex complement, etc.
Gen Generalization.
GG Gain graphs, voltage graphs, biased graphs; includes Dowling lattices.
I Incidence matrix, Kirchhoff matrix.
LG Line graphs.
M Matroids, chain-groups, flows.
N Numerical and algebraic invariants of signed graphs, etc.
O Orientations, bidirected graphs.
P All-negative or antibalanced signed graphs; parity-biased graphs.
Ref Many references.
S Signed objects other than graphs and hypergraphs: mathematical properties.
SD Signed digraphs: mathematical properties.
SG Signed graphs: mathematical properties.
Str Structure theory.
Sw Switching of signs or gains.
TG Two-graphs, graph (Seidel) switching (partial coverage).
VS Vertex-signed graphs ("marked graphs"); signed vertices and edges.
X Extremal problems.

B. Devadas Acharya

1980b An extension of the concept of clique graphs and the problem of K-convergence to signed graphs. *Nat. Acad. Sci. Letters (India)* 3 (1980), 239–242. Zbl. 491.05052. **(SG: LG, Clique graph)**

1982a Connected graphs switching equivalent to their iterated line graphs. *Discrete Math.* 41 (1982), 115–122. MR 84b:05078. Zbl. 497.05052. **(LG, TG)**

M. Behzad and G. Chartrand

1969a Line-coloring of signed graphs. *Elem. Math.* 24 (1969), 49–52. MR 39 #5415. Zbl. 175, 503 (e: 175.50302). **(SG: LG: Cl)**

F.C. Bussemaker, D.M. Cvetković, and J.J. Seidel

1976a Graphs related to exceptional root systems. T.H.-Report 76-WSK-05, 91 pp. Dept. of Math., Technological Univ. Eindhoven, Eindhoven, The Netherlands, 1976.

The 187 simple graphs with eigenvalues ≥ -2 that are not (negatives of) reduced line graphs of signed graphs are found, with computer aid. All are represented by root systems E_d, $d = 6, 7, 8$ (by Cameron, Goethals, Seidel, and Shult 1976a). Most interesting is Thm. 2: each such graph is Seidel-switching equivalent to a line graph of a graph. [*Problem.* Explain this within signed graph theory.] **(LG: p: A)**

1976b Graphs related to exceptional root systems. In: A. Hajnal and Vera T. Sós, eds., *Combinatorics* (Proc. Fifth Hungar. Colloq., Keszthely, 1976), Vol. 1, pp. 185–191. Colloq. Math. Soc. János Bolyai, 18. North-Holland, Amsterdam, 1978. MR 80g:05049. Zbl. 392.05055.

Announces the results of (1976a). **(LG: p: A)**

1980b An extension of the concept of clique graphs and the problem of K-convergence to signed graphs. *Nat. Acad. Sci. Letters (India)* 3 (1980), 239–242. Zbl. 491.05052. **(SG: LG, Clique graph)**

Peter J. Cameron

1980a A note on generalized line graphs. *J. Graph Theory* 4 (1980), 243–245. MR 81j:05089. Zbl. 403.05048, (427.05039).

[For generalized line graphs see Zaslavsky (1984c).] If two generalized line graphs are isomorphic, their underlying graphs and cocktail-party attachments are isomorphic, with small exceptions related to exceptional isomorphisms and automorphisms of root systems. The proof, along the lines of Cameron, Goethals, Seidel, and Shult (1976a), employs the canonical vector representation of the underlying signed graph. **(sg: LG: Aut)**

P.J. Cameron, J.M. Goethals, J.J. Seidel, and E.E. Shult

††1976a Line graphs, root systems, and elliptic geometry. *J. Algebra* 43 (1976), 305–327. MR 56 #182. Zbl. 337.05142. Reprinted in Seidel (1991a), pp. 208–230.

The essential idea is that graphs with least eigenvalue ≥ -2 are represented by the angles of root systems. It follows that line graphs are so represented. [Similarly, signed graphs with largest eigenvalue ≤ 2 are represented by the inner products of root systems, as in Vijayakumar *et al.* These include the line graphs of signed graphs as in Zaslavsky (1984c), since simply signed graphs are represented by B_n or C_n with a few exceptions. The representation of ordinary graphs by all-negative signed graphs is motivated in Zaslavsky (1984c).] **(LG: sg: A, G, Sw)**

P.J. Cameron, J.J. Seidel, and S.V. Tsaranov

1994a Signed graphs, root lattices, and Coxeter groups. *J. Algebra* 164 (1994), 173–209. MR 95f:20063. Zbl. 802.05043.

A generalized Coxeter group $\mathrm{Cox}(\Sigma)$ and a Tsaranov group $\mathrm{Ts}(\Sigma)$ are defined via Coxeter relations and an extra relation for each negative polygon in Σ. They generalize Coxeter groups of tree Coxeter graphs and the Tsaranov groups of a two-graph ($|\Sigma| = K_n$; see Seidel and Tsaranov (1990a)). A new operation of "local switching" is introduced, which changes the edge set of Σ but preserves the associated groups.

§2, "Signed graphs", proves some well-known properties of switching and reviews interesting data from Bussemaker, Cameron, Seidel, and Tsaranov (1991a). §3, "Root lattices and Weyl groups": The "intersection matrix" $2I + A(\Sigma)$ is a hyperbolic Gram matrix of a basis of $\mathbb{R}^n$ whose vectors form only angles $\pi/2, \pi/3, 2\pi/3$. To these vectors are associated the lattice $L(\Sigma)$ of their integral linear combinations and the Weyl group $W(\Sigma)$ generated by reflecting along the vectors. W is finite iff $2I + A(\Sigma)$ is positive definite (Thm. 3.1). *Problem* 3.6. Determine which Σ have this property. §4 introduces local switching to partially solve *Problem* 4.1: Which signed graphs generate the same lattice? Results and some experimental data are reported. All-negative signed graphs play a special role. §6, "Coxeter groups": The relationship between the Coxeter and Weyl groups of Σ. $\mathrm{Cox}(\Sigma)$ is $\mathrm{Cox}(|\Sigma|)$ with additional relations for antinegative (i.e., negative in $-\Sigma$) induced polygons. §7: "Signed complete graphs". §8: "Tsaranov groups" of signed K_n's §9: "Two-graphs arising from trees" (as in Seidel and Tsaranov (1990a)).

Dictionary: "(Γ, f)" $= \Sigma = (\Gamma, \sigma)$. "Fundamental signing" = all-negative signing, giving the antibalanced switching class. "The balance" of a cycle (i.e., polygon) = its sign $\sigma(C)$; "the parity" $= \sigma(-C)$ where $-C = C$ with all signs negated. "Even" = positive and "odd" = negative (referring to "parity"). "The balance" of Σ = the partition of all polygons into positive and negative classes $\mathcal{C}^+$ and $\mathcal{C}^-$; this is the bias on $|\Sigma|$ due to the signing and should not be confused with the customary meaning of "balance", i.e., all polygons are positive.

[A more natural definition of the intersection matrix would be $2I - A$. Then signs would be negative to those in the paper. The need for "parity" would be obviated, ordinary graphs would correspond to all-positive signings (and those would be "fundamental"), and the extra Coxeter relations would pertain to negative induced polygons.] **(SG: A, G, Sw(Gen), lg)**

P.D. Chawathe and G.R. Vijayakumar

1990a A characterization of signed graphs represented by root system D_∞. *European J. Combin.* 11 (1990), 523–533. MR 91k:05071. Zbl. 764.05090. **(SG: G)**

Dragoš Cvetković, Michael Doob, and Slobodan Simić

1980a Some results on generalized line graphs. *C. R. Math. Rep. Acad. Sci. Canada* 2 (1980), 147–150. MR 81f:05136. Zbl. 434.05057.

Abstract of (1981a). **(sg: LG, A(LG), Aut(LG))**

1981a Generalized line graphs. *J. Graph Theory* 5 (1981), 385–399. MR 82k:05091. Zbl. 475.05061. **(sg: LG, A(LG), Aut(LG))**

Dragoš M. Cvetković and Slobodan K. Simić

1978a Graphs which are switching equivalent to their line graphs. *Publ. Inst. Math. (Beograd) (N.S.)* 23 (37) (1978), 39–51. MR 80c:05108. Zbl. 423.05035. **(sw: LG)**

Michael Doob

See also D.M. Cvetković.

1970a A geometric interpretation of the least eigenvalue of a line graph. In: *Proc. Second Chapel Hill Conference on Combinatorial Mathematics and Its Applications* (1970), pp. 126–135. Univ. of North Carolina at Chapel Hill, Chapel Hill, N.C., 1970. MR 42 #2959. Zbl. 209, 554 (e: 209.55403).

A readable, tutorial introduction to (1973a) (without matroids). **(ec: LG, I, A(LG))**

1973a An interrelation between line graphs, eigenvalues, and matroids. *J. Combin. Theory Ser. B* 15 (1973), 40–50. MR 55 #12573. Zbl. 245.05125, (257.05132).

Along with Simões-Pereira (1973a), introduces to the literature the even-cycle matroid $G(-\Gamma)$ [previously invented by Tutte, unpublished]. The multiplicity of -2 as an eigenvalue (in characteristic 0) equals the number of independent even polygons $= n - \operatorname{rk} G(-\Gamma)$. In characteristic p there is a similar theorem, but the pertinent matroid is $G(\Gamma)$ if $p = 2$ and, when $p|n$, the matroid has rank 1 greater than otherwise [a fact that mystifies me]. **(EC: LG, I, A(LG))**

Michael Doob and Dragoš Cvetković

1979a On spectral characterizations and embeddings of graphs. *Linear Algebra Appl.* 27 (1979), 17–26. MR 81d:05050. Zbl. 417.05025. **(sg: LG, A(LG))**

Mukhtiar Kaur Gill [Mukti Acharya]

1982a Contributions to Some Topics in Graph Theory and Its Applications. Ph.D. thesis, Dept. of Mathematics, Indian Institute of Technology, Bombay, 1982.

Most of the results herein have been published separately. See Gill (1981a, 1981b), Gill and Patwardhan (1981a, 1983a, 1986a). **(SG, SD: B, LG, A)**

M.K. Gill and G.A. Patwardhan

1981a A characterization of sigraphs which are switching equivalent to their line sigraphs. *J. Math. Phys. Sci.* 15 (1981), 567–571. MR 84h:05106. Zbl. 488.05054. **(SG: LG)**

1982a A characterization of sigraphs which are switching equivalent to their iterated line sigraphs. *J. Combin. Inform. System. Sci.* 7 (1982), 287–296. MR 86a:05103. Zbl. 538.05060. **(SG: LG)**

P.L. Hammer, N.V.R. Mahadev, and U.N. Peled

1989a Some properties of 2-threshold graphs. *Networks* 19 (1989), 17–23. MR 89m:05096. Zbl. 671.05059.

A restricted line graph with signed edges is a proof tool. **(SG, LG)**

Frank Harary and Michael Plantholt

1983a The derived signed graph of a digraph. *Expositiones Math.* 1 (1983), 343–347. MR 86h:05056. Zbl. 525.05030. **(SG: LG, B)**

Robert L. Hemminger and Joseph B. Klerlein

1979a Line pseudodigraphs. *J. Graph Theory* 1 (1977), 365–377. MR 57 #5812. Zbl. 379.05032.

An attempt, intrinsically unsuccessful, to represent the (signed) line graph of a digraph (see Zaslavsky 20xxb) by a digraph. [Continued by Klerlein (1975a).] **(sg: LG, o)**

Robert L. Hemminger and Bohdan Zelinka

1973a Line isomorphisms on dipseudographs. *J. Combin. Theory Ser. B* 14 (1973), 105–121. MR 47 #3230. Zbl. 263.05107. **(sg: LG, o)**

Alan J. Hoffman

1970a $-1-\sqrt{2}$? In: Richard Guy *et al.*, eds., *Combinatorial Structures and Their Applications* (Proc. Calgary Internat. Conf., 1969), pp. 173–176. Gordon and Breach, New York, 1970. Zbl. 262.05133. **(LG)**

1976a On spectrally bounded signed graphs. (Abstract.) *Trans. Twenty-First Conf. of Army Mathematicians* (White Sands, N.M., 1975), pp. 1–5. ARO Rep. 76-1. U. S. Army Research Office, Research Triangle Park, N.C., 1976. MR 58 #27648.
Abstract of (1977b). **(SG: LG)**

1977a On graphs whose least eigenvalue exceeds $-1-\sqrt{2}$. *Linear Algebra Appl.* 16 (1977), 153–165. MR 57 #9607. Zbl. 354.05048. **(LG)**

1977b On signed graphs and gramians. *Geometriae Dedicata* 6 (1977), 455–470. MR 57 #3167. Zbl. 407.05064. **(SG: LG)**

Joseph B. Klerlein

See also R.L. Hemminger.

1975a Characterizing line dipseudographs. In: F. Hoffman *et al.*, eds., *Proceedings of the Sixth Southeastern Conference on Combinatorics, Graph Theory and Computing* (Boca Raton, 1975), pp. 429–442. Congressus Numerantium, XIV. Utilitas Math. Publ. Inc., Winnipeg, Man., 1975. MR 53 #190. Zbl. 325.05106.
Continues the topic of Hemminger and Kerlein (1977a). **(sg: LG, o)**

Luigi Muracchini and Anna Maria Ghirlanda

1965a Sui grafi segnati ed i grafi commutati. *Statistica* (Bologna) 25 (1965), 677–680. MR 33 #7272.
A partially successful attempt to use unoriented signed graphs to define a line graph of a digraph. [See Zaslavsky (20xxb) for the correct signed-graph approach.] The Harary-Norman line digraph is also discussed. **(SG: B, LG)**

S.B. Rao, N.M. Singhi, and K.S. Vijayan

1981a The minimal forbidden subgraphs for generalized line graphs. In: S.B. Rao, ed., *Combinatorics and Graph Theory* (Proc. Sympos., Calcutta, 1980), pp. 459–472. Lecture Notes in Math., 885. Springer-Verlag, Berlin, 1981. MR 83i:05062. Zbl. 494.05053.
(sg: LG, p)

D.K. Ray-Chaudhuri, N.M. Singhi, and G.R. Vijayakumar

1992a Signed graphs having least eigenvalue around -2. *J. Combin. Inform. System Sci.* 17 (1992), 148–165. MR 94g:05056. **(SG: A, G: Exp)**

Slobodan K. Simić

See also D.M. Cvetković.

1980a Graphs which are switching equivalent to their complementary line graphs I. *Publ. Inst. Math. (Beograd) (N.S.)* 27 (41) (1980), 229–235. MR 82m:05077. Zbl.

531.05050. (**TG: LG**)

1982a Graphs which are switching equivalent to their complementary line graphs II. *Publ. Inst. Math. (Beograd) (N.S.)* 31 (45) (1982), 183–194. MR 85d:05207. Zbl. 531.05051. (**TG: LG**)

N.M. Singhi

See also S.B. Rao, D.K. Ray-Chaudhuri, and G.R. Vijayakumar.

N.M. Singhi and G.R. Vijayakumar

1992a Signed graphs with least eigenvalue < -2. *European J. Combin.* 13 (1992), 219–220. MR 93e:05069. Zbl. 769.05065. (**SG: A**)

Aleksandar Torgašev

See also D.M. Cvetković.

1982a The spectrum of line graphs of some infinite graphs. *Publ. Inst. Math. (Beograd) (N.S.)* 31 (45) (1982), 209–222. MR 85d:05175. Zbl. 526.05039.

An infinite analog of Doob's (1973a) characterization via the even-cycle matroid of when a line graph has -2 as an eigenvalue. [*Problem.* Generalize to line graphs of infinite signed graphs.] (**p: A(LG)**)

1983a A note on infinite generalized line graphs. In: D. Cvetković *et al.*, eds., *Graph Theory* (Proc. Fourth Yugoslav Seminar, Novi Sad, 1983), pp. 291–297. Univ. Novom Sadu, Inst. Mat., Novi Sad, 1984. MR 85i:05168. Zbl. 541.05042.

An infinite graph is a generalized line graph iff its least "limit" eigenvalue ≥ -2. [*Problem.* Generalize to line graphs of infinite signed graphs.] (**p: A(LG)**)

G.K. Vijayakumar

See G.R. Vijayakumar.

G.R. Vijayakumar

See also P.D. Chawathe, D.K. Ray-Chaudhuri, and N.M. Singhi.

1984a (As "G.K. Vijayakumar") A characterization of generalized line graphs and classification of graphs with eigenvalues at least 2 [misprint for -2]. *J. Combin. Inform. Syst. Sci.* 9 (1984), 182–192. MR 89g:05055. Zbl. 629.05046. (**sg: A, lg**)

1987a Signed graphs represented by D_∞. *European J. Combin.* 8 (1987), 103–112. MR 88b:05111. Zbl. 678.05058. (**SG: A, G, lg**)

1992a Signed graphs represented by root system E_8. Combinatorial Math. and Appl. (Proc., Calcutta, 1988). *Sankhya Ser. A* 54 (1992), 511–517. MR 94d:05072. Zbl. 882.05118. (**SG: A, G**)

1993a Algebraic equivalence of signed graphs with all eigenvalues ≥ -2. *Ars Combin.* 35 (1993), 173–191. MR 93m:05134. Zbl. 786.05059. (**SG: A, G**)

1994a Representation of signed graphs by root system E_8. *Graphs Combin.* 10 (1994), 383–388. MR 96a:05128. Zbl. 821.05040. (**SG: G**)

G.R. Vijayakumar and N.M. Singhi

1990a Some recent results on signed graphs with least eigenvalues ≥ -2. In: Dijen Ray-Chaudhuri, ed., *Coding Theory and Design Theory Part I: Coding Theory* (Proc. Workshop IMA Program Appl. Combin., Minneapolis, 1987–88), pp. 213–218. IMA Vol. Math. Appl., 20. Springer-Verlag, New York, 1990. MR 91e:05069. Zbl. 711.05033. (**SG: G, lg: Exp**)

G.R. Vijayakumar (as "Vijaya Kumar"), S.B. Rao, and N.M. Singhi

1982a Graphs with eigenvalues at least -2. *Linear Algebra Appl.* 46 (1982), 27–42. MR 83m:05099. Zbl. 494.05044. **(sg: A, G, lg)**

K.S. Vijayan

See S.B. Rao.

Thomas Zaslavsky

1984c Line graphs of switching classes. In: *Report of the XVIIIth O.S.U. Denison Maths Conference* (Granville, Ohio, 1984), pp. 2–4. Dept. of Math., Ohio State Univ., Columbus, Ohio, 1984.

The line graph of a switching class $[\Sigma]$ of signed graphs is a switching class of signed graphs; call it $[L'(\Sigma)]$. The reduced line graph L is formed from L' by deleting parallel pairs of oppositely signed edges. Then $A(L) = A(L') = 2I - MM^{\mathrm{T}}$, where M is the incidence matrix of Σ. Thm. 1: $A(L)$ has all eigenvalues ≤ 2. Examples: For an ordinary graph Γ, $L(-\Gamma) = -L(\Gamma)$. Taking $-\Gamma$ and attaching any number of pendant negative digons to each vertex yields (the negative of) Hoffman's generalized line graph. Additional results are claimed but there are no proofs. [See also 20xxb).] [This work is intimately related to that of Vijayakumar *et al.*, which was then unknown to the author, and to Cameron, Goethals, Seidel, and Shult (1976a).]

(SG: LG: Sw, A, I)

20xxb Line graphs of signed graphs and digraphs. In preparation. (See: Abstract 768-05-3, Line graphs of digraphs. *Notices Amer. Math. Soc.* 26, No. 5 (August, 1979), A-448.)

Line graphs of signed graphs are, fundamentally, (bidirected) line graphs of bidirected graphs. Then the line graph of a signed graph is a polar graph, i.e., a switching class of bidirected graphs; the line graph of a polar graph is a signed graph; and the line graph of a sign-biased graph, i.e., of a switching class of signed graphs, is a sign-biased graph. In particular, the line graph of an antibalanced switching class is an antibalanced switching class. (Partly for this reason, ordinary graphs should usually be regarded as antibalanced, i.e., all negative, in line graph theory.) Since a digraph is an oriented all-positive signed graph, its line graph is a bidirected graph whose positive part is the Harary-Norman line digraph. Among the line graphs of signed graphs, some reduce by cancellation of parallel but oppositely signed edges to all-negative graphs; these are precisely Hoffman's generalized line graph of ordinary graphs, a fact which explains their line-graph-like behavior. [Attempts at a completely descriptive line graph of a digraph were Muracchini and Ghirlanda (1965a) and Hemminger and Klerlein (1979a). The geometry of line graphs and signed graphs has been developed by Vijayakumar *et al.* See also (1984c).] **(SG: LG: O, I, A(LG). Sw)**

Bohdan Zelinka

See also R.L. Hemminger.

1974a Polar graphs and railway traffic. *Aplikace Mat.* 19 (1974), 169–176. MR 49 #12066. Zbl. 283.05116.

See (1976a) for definitions. Railway tracks and switches modeled by edges and vertices of a polar graph. Forming its derived graph (see (1976d)), thence a digraph obtained therefrom by splitting vertices into two copies and adjusting arcs, the time for a train to go from one segment to another is found by a shortest path calculation in the digraph. A similar method is used to solve the problem for several trains. **(sg: O, sw: LG: Appl)**

1976a Isomorphisms of polar and polarized graphs. *Czechoslovak Math. J.* 26 (101) (1976), 339–351. MR 58 #16429. Zbl. 341.05121.

Basic definitions (Zítek (1972a)): "Polarized graph" B = bidirected graph (with no negative loops and no parallel edges sharing the same bidirection). "Polar graph" $P \cong$ switching class of bidirected graphs (that is, we forget which direction at a vertex is in and which is out—here called "north" and "south" poles—but we remember that they are different).

Thms. 1–6. Elementary results about automorphisms, including finding the automorphism groups of the "complete polarized" and polar graphs. (The "complete polarized graph" has every possible bidirected link and positive loop, without repetition.) Thm. 7: With small exceptions, any (ordinary) graph can be made polar as, say, P so that $\operatorname{Aut} P$ is trivial.

Thms. 8–10. Analogs of Whitney's theorem that the line graph almost always determines the graph. The "pole graph" B^* of B or $[B]$: Split each vertex into an "in" copy and an "out" copy and connect the edges appropriately. [Generalizes splitting a digraph into a bipartite graph. It appears to be a "twisted" signed double covering graph.] Thm. 8. The pole graph is determined, with two exceptions, by the edge relation $e \sim_1 f$ if both enter or both leave a common vertex. (A trivial consequence of Whitney's theorem.) Thm. 9. A polar graph $[B]$ with enough edges going in and out at each vertex is determined by the edge relation $e \sim_2 f$ if one enters and the other exits a common vertex. (Examples show that too few edges going in and out leave $[B]$ undetermined.) Thm. 10. Knowing $\sim_1$, $\sim_2$, and which edges are parallel with the same sign, and if no component of the simplified underlying graph of B is one of twelve forbidden graphs, then $[B]$ is determined. [*Problem* 1. Improve Thm. 10 to a complete characterization of the bidirected graphs that are reconstructible from their line graphs (which are to be taken as bidirected; see Zaslavsky (1984c, 20xxb)). In connection with this, see results on characterizing line graphs of bidirected (or signed) graphs by Vijayakumar (1987a). *Problem* 2. It would be interesting to improve Thm. 9.] **(sg: O, sw: Aut, lg)**

1976d Self-derived polar graphs. *Czechoslovak Math. J.* 26 (101) (1976), 365–370. MR 58 #16431. Zbl. 341.05124.

See (1976a) for basic definitions. The "derived graph" of a bidirected graph [this is equivalent to the author's terminology] is essentially the positive part of the bidirected line graph. The theorem can be restated, somewhat simplified: A finite connected bidirected graph B is isomorphic to its derived graph iff B is balanced and contains exactly one polygon. **(sg: O, sw: LG)**