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Bifurcations – Sights, Sounds, and Mathematics

Springer-Verlag, Tokyo – Berlin – New York 1993.
468 pages, 138 figures, 31 color plates, bibliography (298 items).
ISBN 4-431-70120-6 (Tokyo), 3-540-70120-6 (Berlin), 0-387-70120-6 (New York).

Bifurcation, from Latin "bifurcatio" means splitting into two parts. Dynamical system with a scalar real parameter (generally vector parameter with real components) may evolve in qualitative different ways during small change of the parameter — such change is called the bifurcation. The basis of the bifurcation theory were founded by Poincaré and Lyapunov. The bifurcation is in intimate way known to electronic and control engineers through classical Bode-Evans root locus method — for the root locus crossing the stability boundary.

Part 1 "Bifurcations observed from electronic circuits" (139 pp.) is concerned with Lur'e systems, i.e. linear dynamical single-input, single-output systems with scalar static nonlinear feedback. In Part 1 only piecewise-linear (PWL) nonlinearity is considered — the trick used for the analysis already by Birkhoff. It was Matsumoto who tuned in 1983 the 3rd order electronic circuit, designed by Chua as potentially chaotic, to bifurcate to behave in a chaotic way. See both Matsumoto: A chaotic attractor from Chua circuit, IEEE Trans. *CAS-31* (1984), 1055–1058, and Chua: The genesis of Chua's circuit, AEÜ *46* (1992), 250–257. The reviewer started his research on chaotic systems in 1988, when Prof. Matsumoto sent him the op-amp realization of Prof. Chua circuit. The concrete electronic circuits analyzed in Part 1 are the double scroll or Chua circuit (in greatest detail), the torus breakdown circuit, the hyperchaotic circuit, the neon bulb circuit and the *R-L*-diode circuit. All of these are Lur'e type circuits — although the control theorist Lur'e is never mentioned by the authors which are the circuit theorists.

Part 2 "Bifurcations of continuous piecewise-linear vector fields" (146 pp). Now the static PWL feedback is generalized to a vector PWL feedback. This makes possible to successfully piecewise-linearly approximate even non-Lur'e circuits such as systems of Lorenz and Duffing. Several normal forms are given. In general, the connection between the various neighbourhoods of hyperbolic equilibria points is given by the heteroclinic trajectory: this is the rise of the chaotic behavior which is analytically provable but not observable. Observable chaos is far from heteroclinicity. This part is quite detailed and sophisticated.

Part 3 "Fundamental concepts in bifurcations" (148 pp). Now the PWL type of nonlinearity is put apart. This is a review part. The main tools are Hartman-Grobman theorem: "A vector field around a hyperbolic equilibrium point is locally topologically equivalent to the linearized vector field at the equilibrium point", the stable and center manifold theorems, and the theorems on bifurcations.

The authors are subtile and distinguished analysts of the chaos but they are missing the synthesis problem. In quoted article on the genesis of his circuit, Chua reminds his invention of potentially chaotic circuit: "Suddently it dawned to upon me, that since the main mechanism which gives rise to chaos, in both Lorenz and the Rössler Equations, is the presence of at least two *unstable* equilibrium points – 3 for Lorenz Equations and 2 for the Rössler Equations – it seems only prudent to design a simpler and more robust circuit having these atributes. Having identified this alternative approach and strategy, it becomes a simple exercise in elementary nonlinear circuit theory to enumerate systematically *all* such circuit candidates. [...] This simple exercise quickly led [...] me to [Chua] circuit".

The reviewer quotes more recent result on chaos synthesis scenario, Vaněček, Čelikovský: "Let us choose: (i) the linear system with a single input and a single output, at least of the third order, with the poles that are semistable, hyperbolic, dissipative, and nonpotential; (ii) the feedback from the output to the input which is nonlinear, static, odd, and strictly monotonous, giving rise in addition to the central equilibrium also the off-central equilibria; (iii) the linear system zeros, which are attracting, according to the rules of the root locus method, the central equilibrium poles to the off-central equilibria poles in such a way that these off-central equilibria poles are again semistable, hyperbolic, nonpotential, and dissipative", Chaos synthesis via root locus, IEEE Trans. Circuit Systems–I, *41* (1994), 59–60.

The book of Matsumoto *et al.* is to be highly recommended for its concrete and inductive character of exposition (– demonstrated by its subtitle as well) of this new field of chaotic systems.

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