MASTER SAR

SUPELEC – ENS CACHAN – UNIVERSITY PARIS–SUD 11

Research Seminar
Professor in charge: Antoine O. BERTHET
Scheduled volume: 12H

Reference	**Codes on Graphs**
SAR–S2	Lecturer: A.O. BERTHET

Codes on Graphs and Iterative Decoding

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Time: S4 / 12H
Location: SUPELEC – Department of Telecommunications
Reception hours: After class or by setting an appointment (e-mail)
Pre–requisites: SAR-B1, SAR-B2, SAR-C1, SAR-C3
Grading: Final project
Homework: Complementary bibliographical search

Abstract
A recurrent problem for scientists consists to evaluate the marginals of joint probability distributions, in which thousands or even millions of (either discrete or continuous) random variables are linked in complex ways. For that purpose, similar algorithms have been independently thought in areas as diverse as error-correction coding theory, statistical physics, artificial intelligence or bioinformatics. The well-known BCJR (or forward-backward) algorithm, Gallager's algorithms used to decode LDPC codes and the Berrou et al.'s iterative algorithm used to decode to turbo codes are famous examples in coding theory. Recently, it has been pointed out that all those algorithms could in fact be seen as instances of a very generic algorithm, often referred to as sum-product algorithm, which computes and propagates messages (summaries) along the edges of an appropriate graph-theoretic representation of the joint probaility distribution (e.g., a factor graph). Depending on the topology of the graph (i.e., acyclic or with cycles), the algorithm delivers exact or approximate marginals. More involved procedures able to solve complex problems like joint parameter estimation, detection/equalization and decoding in an efficient (iterative) way can similarly be derived as particular forms of the sum-product algorithm operating on dense layered hybrid factor graphs with cycles assuming specific schedules and a number of approximations on the nature of exchanged messages. Using the unified and powerful framework of initially proposed by Kschischang, Frey and Loeliger and extending the views of Worthen and Stark, this course draws a survey of the most recent advances in terms of iterative processing. The course sometimes leaves out convergence proofs or per-iteration performance analyses, which, in the considered real-world applications, constitute very hard largely open issues even now.

Tentative syllabus
- Background material: Bridges between coding theory and graph theory.
- Graphical models: Factor graphs and the sum-product algorithm.

- LDPC codes and their generalizations (Tanner's formalism): Setting and notation, design aspects, tree property for the asymptotic analysis, concentration inequalities, asymptotic analysis, stopping sets.
- Advanced information processing in digital communications (turbo principle).
- Bridges with statistical physics.

References

[1] GALLAGER, R.G., *Information Theory and Reliable Communications*, Wiley, 1968.
[2] GALLAGER, R.G., *Low Density Parity Check Codes*, MIT Press, 1963.
[3] PEARL, J., *Probabilistic Reasoning and Intelligent Systems: Networks of Plausible Inference*, Morgan Kaufmann Publishers, 1988.
[4] JORDAN, M.I., *Learning in Graphical Models*, Kluwer Academic Publishers, 1998.
[5] MACKAY, D.J.C., *Information Theory, Inference and Learning Algorithms*, Cambridge University Press, 2003.
[6] RICHARDSON, T., and URBANKE, R., *Modern Coding Theory*, Cambridge University Press, 2008.
[7] MEZARD, M., and MONTANARI, A., *Information, Physics and Computation*, Oxford University Press, 2008.
[8] Special issue, IEEE Trans. Information Theory, Feb. 2001.
[9] *Concatenated Coding and Iterative Decoding: Sailing toward Channel Capacity*, IEEE J. Sel. Area. Commun., Special issue, Feb. 1998.
[10] *The Turbo-Principle: From Theory to* Practice, Special issue, Part I, IEEE J. Sel. Area. Commun., May. 2001.
[11] *The Turbo-Principle: From Theory to* Practice, Special issue, Part II, Special issue, IEEE J. Sel. Area. Commun., Sept. 2001.
[12] *Capacity Approaching* Codes, Special issue, IEEE J. Sel. Area. Commun., Aug. 2009.