



Universiteit
Leiden
The Netherlands

Uniform infinite and Gibbs causal triangulations

Zohren, S.

Citation

Zohren, S. (2012, December 19). *Uniform infinite and Gibbs causal triangulations*. Retrieved from <https://hdl.handle.net/1887/20324>

Version: Corrected Publisher's Version

License: [Licence agreement concerning inclusion of doctoral thesis in the Institutional Repository of the University of Leiden](#)

Downloaded from: <https://hdl.handle.net/1887/20324>

Note: To cite this publication please use the final published version (if applicable).

Cover Page



Universiteit Leiden



The handle <http://hdl.handle.net/1887/20324> holds various files of this Leiden University dissertation.

Author: Zohren, Stefan

Title: Uniform infinite and Gibbs causal triangulations

Date: 2012-12-19

Bibliography

- [1] M. Weigel, *Vertex models on random graphs*. PhD thesis, Universität Leipzig, 2002.
- [2] R. Loll, W. Westra, and S. Zohren, “Nonperturbative sum over topologies in 2D Lorentzian quantum gravity,” *AIP Conf. Proc.* **861** (2006) 391–397, [hep-th/0603079](#).
- [3] W. T. Tutte, “A census of planar maps,” *Can. J. Math.* **15** (1963) 249–271.
- [4] W. T. Tutte, “A census of planar triangulations,” *Can. J. Math.* **14** (1962) 21–38.
- [5] W. T. Tutte, “A census of slicings,” *Can. J. Math.* **14** (1962) 798–722.
- [6] W. T. Tutte, “A census of hamiltonian polygons,” *Can. J. Math.* **14** (1962) 402–417.
- [7] G. ’t Hooft, “A planar diagram theory for strong interactions,” *Nucl. Phys.* **B72** (1974) 461.
- [8] E. Brezin, C. Itzykson, G. Parisi, and J. B. Zuber, “Planar diagrams,” *Commun. Math. Phys.* **59** (1978) 35.
- [9] J. Ambjørn, B. Durhuus, and T. Jonsson, *Quantum geometry. A statistical field theory approach*. No. 1 in Cambridge Monogr. Math. Phys., Cambridge University Press, Cambridge, UK, 1997.
- [10] J. Ambjørn and R. Loll, “Non-perturbative Lorentzian quantum gravity, causality and topology change,” *Nucl. Phys.* **B536** (1998) 407–434, [hep-th/9805108](#).
- [11] J. Ambjørn, R. Loll, Y. Watabiki, W. Westra, and S. Zohren, “New aspects of two-dimensional quantum gravity,” *Acta Phys. Polon.* **B40** (2009) 3479–3507, [0911.4208](#).
- [12] J. Ambjorn, A. Goerlich, J. Jurkiewicz, and R. Loll, “Nonperturbative Quantum Gravity,” [1203.3591](#).
- [13] T. Coulhon, “Random walks and geometry on infinite graphs,” in *Lecture notes on analysis on metric spaces*, L. Ambrosio and F. S. Cassano, eds. 2000.
- [14] O. Angel and O. Schramm, “Uniform infinite planar triangulations,” *Comm. Math. Phys.* **241** (2003) 191–213, [math/0207153](#).
- [15] O. Angel, “Growth and percolation on the uniform infinite planar triangulation,” *Geom. Func. Analysis* **13** (2003) 935–974.

- [16] P. Chassaing and B. Durhuus, “Local limit of labeled trees and expected volume growth in a random quadrangulation,” *Annals of Probability* **34** (2006) 879.
- [17] M. Krikun, “Uniform infinite planar triangulation and related time-reversed critical branching process,” *J. Math. Sci.* **131** (2005) 5520–5537.
- [18] M. Krikun, “Local structure of random quadrangulations,” *Preprint* (2005) [math/0512304](#).
- [19] I. Benjamini and O. Schramm, “Recurrence of distributional limits of finite planar graphs,” *Electron. J. Probab* **6** (2001) 1, [math/0011019](#).
- [20] I. Benjamini and N. Curien, “Simple random walk on the uniform infinite planar quadrangulation: Subdiffusivity via pioneer points,” *Preprint* (2012) [1202.5454](#).
- [21] J. F. Le Gall and G. Miermont, “Scaling limits of random trees and planar maps,” in *Clay Mathematics Summer School 2010*. 2011. [1101.4856](#).
- [22] R. Cori and B. Vauquelin, “Planar maps are well labeled trees,” *Canad. J. Math.* **33** (1981) 1023.
- [23] G. Schaeffer, *Conjugaison d'arbres et cartes combinatoires aléatoires*. PhD thesis, Université de Bordeaux I, 1998.
- [24] J. Bouttier, P. Di Francesco, and E. Guitter, “Planar maps as labeled mobiles,” *Elec. J. Comb.* **11** (2004) R69.
- [25] D. Aldous, “The continuum random tree. I,” *Ann. Probab.* **19** (1991), no. 1, 1–28.
- [26] J.-F. Marckert and A. Mokkadem, “Limit of normalized random quadrangulations: the brownian map,” *Annals of Probability* **34** (2006) 2144.
- [27] G. Miermont, “The brownian map is the scaling limit of uniform random plane quadrangulations,” *Preprint* (2011) [1104.1606](#).
- [28] J. F. Le Gall, “Uniqueness and universality of the brownian map,” *Preprint* (2011) [1105.4842](#).
- [29] J.-F. Le Gall and F. Paulin, “Scaling limits of bipartite planar maps are homeomorphic to the 2-sphere,” *Geom. Funct. Anal.* **18** (2008) 893.
- [30] G. Miermont, “On the sphericity of scaling limits of random planar quadrangulations,” *Electron. Commun. Probab.* **13** (2008) 248.
- [31] J.-F. Le Gall, “The topological structure of scaling limits of large planar maps,” *Invent. Math.* **169** (2007) 621.
- [32] P. Di Francesco, E. Guitter, and C. Kristjansen, “Integrable 2D Lorentzian gravity and random walks,” *Nucl. Phys.* **B567** (2000) 515–553, [hep-th/9907084](#).
- [33] V. Malyshev, A. Yambartsev, and A. Zamyatin, “Two-dimensional Lorentzian models,” *Moscow Mathematical Journal* **1** (2001), no. 2, 1–18.
- [34] B. Durhuus, T. Jonsson, and J. F. Wheeler, “On the spectral dimension of causal triangulations,” *J. Stat. Phys.* **139** (2009) 859–881, [0908.3643](#).

- [35] K. Athreya and P. Ney, *Branching Processes*. Springer Verlag, 1972.
- [36] D. P. Kennedy, “The Galton-Watson process conditioned on the total progeny,” *J. Appl. Probability* **12** (1975) 800–806.
- [37] D. Aldous and J. Pitman, “Tree-valued Markov chains derived from Galton-Watson processes,” *Ann. Inst. H. Poincaré Probab. Statist.* **34** (1998) 637–686.
- [38] A. Meir and J. W. Moon, “On the altitude of nodes in random trees,” *Canad. J. Math.* **30** (1978), no. 5, 997–1015.
- [39] B. Durhuus, T. Jonsson, and J. F. Wheeler, “The spectral dimension of generic trees,” *J. Stat. Phys.* **128** (2007), no. 5, 1237–1260, [math-ph/0607020](#).
- [40] J. Ambjørn, D. Boulatov, J. L. Nielsen, J. Rolf, and Y. Watabiki, “The spectral dimension of 2D quantum gravity,” *JHEP* **02** (1998) 010, [hep-th/9801099](#).
- [41] T. Jonsson and J. F. Wheeler, “The spectral dimension of the branched polymer phase of two-dimensional quantum gravity,” *Nucl. Phys.* **B515** (1998) 549–574, [hep-lat/9710024](#).
- [42] J. Ambjørn, J. Jurkiewicz, and R. Loll, “Spectral dimension of the universe,” *Phys. Rev. Lett.* **95** (2005) 171301, [hep-th/0505113](#).
- [43] M. Barlow and T. Kumagai, “Random walk on the incipient infinite cluster on trees,” *Illinois J. Math.* **50** (2006) 33.
- [44] I. Fujii and T. Kumagai, “Heat kernel estimates on the incipient infinite cluster for critical branching processes,” *Proceedings of German-Japanese symposium in Kyoto 2006* **B6** (2008) 85–95.
- [45] M. T. Barlow, T. Coulhoun, and T. Kumagai, “Characterization of sub-gaussian heat kernel estimates on strongly recurrent,” *Communications on Pure and Applied Mathematics* **58** (2005) 1642–1677.
- [46] D. Croydon and T. Kumagai, “Random walks on Galton-Watson trees with infinite variance offspring distribution conditioned to survive,” *Electronic Journal of Probability* **13** (August, 2008) 1419–1441.
- [47] M. T. Barlow and R. Masson, “Spectral dimension and random walks on the two dimensional uniform spanning tree,” 2009.
- [48] B. Durhuus, T. Jonsson, and J. F. Wheeler, “Random walks on combs,” *J. Phys.* **A39** (2006) 1009–1038, [hep-th/0509191](#).
- [49] J. D. Correia and J. F. Wheeler, “The spectral dimension of non-generic branched polymer ensembles,” *Phys. Lett.* **B422** (1998) 76–81, [hep-th/9712058](#).
- [50] Z. Burda, J. D. Correia, and A. Krzywicki, “Statistical ensemble of scale-free random graphs,” *Phys. Rev.* **E64** (2001) 046118, [cond-mat/0104155](#).
- [51] S. Ö. Stefánsson, “Markov branching in the vertex splitting model,” *Preprint* (2011) 1103.3445.

- [52] M. Krikun and A. Yambartsev, “Phase transition for the Ising model on the critical Lorentzian triangulation,” 0810.2182.
- [53] Y. Watabiki, “Construction of noncritical string field theory by transfer matrix formalism in dynamical triangulation,” *Nucl. Phys.* **B441** (1995) 119–166, hep-th/9401096.
- [54] J. Ambjorn, R. Loll, Y. Watabiki, W. Westra, and S. Zohren, “A causal alternative for $c=0$ strings,” *Acta Phys. Polon.* **B39** (2008) 3355–3364, 0810.2503.
- [55] R. Lyons and Y. Peres, *Probability on Trees and Networks*, vol. in preparation. Cambridge University Press, 2012.
- [56] G. Giasemidis, J. F. Wheeler, and S. Zohren, “Multigraph models for causal quantum gravity and scale dependent spectral dimension,” *J. Phys.* **A45** (2012) 355001, 1202.6322.
- [57] G. Giasemidis, J. F. Wheeler, and S. Zohren, “Dynamical dimensional reduction in toy models of 4D causal quantum gravity,” *Phys. Rev. D* (2012) 1202.2710.
- [58] G. Giasemidis. PhD thesis, University of Oxford, 2013.
- [59] M. G. Krein and M. A. Rutman, “Linear operators leaving invariant a cone in a Banach space,” *Uspekhi Mat. Nauk* **3** (1948) 3.
- [60] D. Aldous, “Probability distributions on cladograms,” in *Random discrete structures*, vol. 76 of *IMA Vol. Math. Appl.*, pp. 1–18. Springer, 1996.
- [61] D. J. Ford, “Probabilities on cladograms: introduction to the alpha model,” 2005.
- [62] F. David, C. Hagendorf, and K. J. Wiese, “A growth model for RNA secondary structures,” *J. Stat. Mech.* (2008) P04008, 0711.3421.
- [63] J.-F. Le Gall, “Random trees and applications,” *Prob. Surveys* **2** (2005) 245–311.
- [64] P. Di Francesco, “2D quantum gravity, matrix models and graph combinatorics,” math-ph/0406013.
- [65] F. David, M. Dukes, T. Jonsson, and S. Ö. Stefánsson, “Random tree growth by vertex splitting,” *J. Stat. Mech.* (2009) P04009, 0811.3183.
- [66] E. Seneta, *Regularly varying functions*. Springer Verlag, 1976.
- [67] W. Feller, *An introduction to probability theory and its applications*, vol. 2. Wiley, 1966.
- [68] W. Feller, “A limit theorem for random variables with infinite moments,” *American Journal of Mathematics* **68** (1946), no. 2, 257–262.
- [69] T. E. Harris, *The theory of branching processes*. Springer-Verlag, Berlin, 1963.
- [70] P. Flajolet and R. Sedgewick, *Analytic combinatorics*. Cambridge University Press, Cambridge, 2009.
- [71] T. Jonsson and S. Ö. Stefánsson, “Condensation in nongeneric trees,” *J. Stat. Phys.* **142** (2011) 277, 1009.1826.

- [72] S. Janson, "Simply generated trees, conditioned Galton–Watson trees, random allocations and condensation," *Preprint* (2011) 1112.0510.
- [73] H. Kesten, "Subdiffusive behavior of random walk on a random cluster," *Ann. Inst. H. Poincaré Probab. Statist.* **22** (1986), no. 4, 425–487.
- [74] R. Slack, "A branching process with mean one and possibly infinite variance," *Z. Wahrscheinlichkeitstheorie verw. Geb.* **9** (1968) 139–145.
- [75] M. Abramowitz and I. A. Stegun, *Handbook of Mathematical Functions, With Formulas, Graphs, and Mathematical Tables*. Dover Publications, 1974.
- [76] B. Chen, D. Ford, and M. Winkel, "A new family of markov branching trees: the alpha-gamma model," 2008.
- [77] J. Ambjørn, K. N. Anagnostopoulos, and R. Loll, "A new perspective on matter coupling in 2d quantum gravity," *Phys. Rev.* **D60** (1999) 104035, hep-th/9904012.
- [78] J. Ambjørn, A. Görlich, J. Jurkiewicz, and R. Loll, "CDT—an entropic theory of quantum gravity," 1007.2560.
- [79] B. Durhuus, "Probabilistic aspects of infinite surfaces and trees," *Act. Phys. Pol.* **34** (2003) 4795–4811.
- [80] J. Lamperti and P. Ney, "Conditioned branching processes and their limiting diffusions," *Theory of Probability and its Applications* **12** (1968) 128–139.
- [81] J. Neveu, "Arbres et processus de Galton-Watson," *Ann. Inst. H. Poincaré Probab. Statist.* **22** (1986), no. 2, 199–207.
- [82] T. Lindvall, "Convergence of critical Galton-Watson branching process," *J. Appl. Prob.* **9** (1972) 445–450.
- [83] T. Lindvall, "Limit theorems for some functionals of certain Galton-Watson branching processes," *Advances in Applied Probability* **6** (1974) 309–321.
- [84] P. Billingsley, *Convergence of probability measures*. Wiley, second ed., 1999.
- [85] S. Ethier and T. Kurtz, *Markov Processes: Characterization and Convergence*. Wiley, 1986.
- [86] A. G. Pakes, "Revisiting conditional limit theorems for the mortal simple branching process," *Bernoulli* **5** (1999) 969–998.
- [87] P. Biane, J. Pitman, and M. Yor, "Probability laws related to the Jacobi theta and Riemann zeta functions, and Brownian excursions," *Bull. Amer. Math. Soc.* **38** (2001) 435–465.
- [88] V. Sisko, A. Yambartsev, and S. Zohren, "A note on weak convergence results for uniform infinite causal triangulations," *Markov Processes and Related Fields* (2012).
- [89] J. Ambjørn, R. Loll, Y. Watabiki, W. Westra, and S. Zohren, "A new continuum limit of matrix models," *Phys. Lett.* **B670** (2008) 224–230, 0810.2408.

- [90] J. Ambjørn, R. Loll, Y. Watabiki, W. Westra, and S. Zohren, “A matrix model for 2D quantum gravity defined by causal dynamical triangulations,” *Phys. Lett.* **B665** (2008) 252–256, 0804.0252.
- [91] S. Zohren, *A Causal Perspective on Random Geometry*. PhD thesis, Imperial College London, 2008. 0905.0213.
- [92] S. S. Gubser and I. R. Klebanov, “Scaling functions for baby universes in two-dimensional quantum gravity,” *Nucl. Phys.* **B416** (1994) 827–849, hep-th/9310098.
- [93] J. Ambjorn, L. Glaser, A. Gorlich, and Y. Sato, “New multicritical matrix models and multicritical 2d CDT,” *Phys.Lett.* **B712** (2012) 109–114, 1202.4435.
- [94] M. R. Atkin and S. Zohren, “An analytical analysis of CDT coupled to dimer-like matter,” *Phys.Lett.* **B712** (2012) 445–450, 1202.4322.
- [95] R. Durrett, *Probability: theory and examples*. Duxbury Press, 1996.
- [96] R. Durrett, *Stochastic Calculus: A Practical Introduction*. CRC Press, 1996.
- [97] D. W. Stroock and S. R. S. Varadhan, *Multidimensional Diffusion Processes*. Springer-Verlag, 1979.
- [98] P. Di Francesco, P. H. Ginsparg, and J. Zinn-Justin, “2-d gravity and random matrices,” *Phys. Rept.* **254** (1995) 1–133, hep-th/9306153.
- [99] G. Schaeffer, “Bijective census and random generation of planar maps: Form the one matrix model solution to a combinatorial proof,” *Elec. J. Comb.* **4** (1997) R20.
- [100] J. Bouttier, P. Di Francesco, and E. Guitter, “Census of planar maps: From the one-matrix model solution to a combinatorial proof,” *Nucl. Phys.* **B645** (2002) 477, cond-mat/0207682.
- [101] V. A. Kazakov, “Ising model on a dynamical planar random lattice: Exact solution,” *Phys. Lett.* **A119** (1986) 140–144.
- [102] D. V. Boulatov and V. A. Kazakov, “The Ising model on random planar lattice: The structure of phase transition and the exact critical exponents,” *Phys. Lett.* **186B** (1987) 379.
- [103] M. Bousquet-Melou and G. Schaeffer, “The degree distribution in bipartite planar maps: applications to the Ising model,” *Preprint* (2002) math/0211070.
- [104] L. Onsager, “Crystal statistics. I. a two-dimensional model with an order-disorder transition,” *Phys. Rev.* **65** (1944) 117.
- [105] V. G. Knizhnik, A. M. Polyakov, and A. B. Zamolodchikov, “Fractal structure of two-dimensional quantum gravity,” *Mod. Phys. Lett.* **A3** (1988) 819.
- [106] B. Duplantier and S. Sheffield, “Schramm loewner evolution and liouville quantum gravity,” *Phys.Rev.Lett.* **107** (2001) 131305, 1012.4800.
- [107] D. Benedetti and R. Loll, “Quantum gravity and matter: Counting graphs on causal dynamical triangulations,” *Gen.Rel.Grav.* **39** (2007) 863, gr-qc/0611075.

- [108] J. Ambjørn, K. N. Anagnostopoulos, R. Loll, and I. Pushkina, “Shaken, but not stirred - Potts model coupled to quantum gravity,” *Preprint* (2008) 0806.3506.
- [109] J. Ambjørn, R. Loll, W. Westra, and S. Zohren, “Putting a cap on causality violations in CDT,” *JHEP* **12** (2007) 017, [arXiv:0709.2784 \[gr-qc\]](#).
- [110] J. Ambjørn, R. Loll, Y. Watabiki, W. Westra, and S. Zohren, “A string field theory based on causal dynamical triangulations,” *JHEP* **05** (2008) 032, 0802.0719.
- [111] M. R. Atkin and S. Zohren, “On the Quantum Geometry of Multi-critical CDT,” *JHEP* **1211** (2012) 037, 1203.5034.
- [112] J. R. Ringrose, *Compact non-self-adjoint operators*. Van Nostrand Reinhold Co., 1971.

