



Universiteit  
Leiden  
The Netherlands

## Enhanced Coinduction

Rot, J.C.

### Citation

Rot, J. C. (2015, October 15). *Enhanced Coinduction*. *IPA Dissertation Series*.  
Retrieved from <https://hdl.handle.net/1887/35814>

Version: Not Applicable (or Unknown)  
License: [Leiden University Non-exclusive license](#)  
Downloaded from: <https://hdl.handle.net/1887/35814>

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

# Bibliography

- [AC14] Davide Ancona and Andrea Corradi. Sound and complete subtyping between coinductive types for object-oriented languages. In Richard Jones, editor, *ECOOP 2014 - Object-Oriented Programming - 28th European Conference, Proceedings*, volume 8586 of *Lecture Notes in Computer Science*, pages 282–307. Springer, 2014. (Cited on page 9.)
- [ACI12] Luca Aceto, Matteo Cimini, and Anna Ingólfssdóttir. Proving the validity of equations in GSOS languages using rule-matching bisimilarity. *Mathematical Structures in Computer Science*, 22(2):291–331, 2012. (Cited on page 160.)
- [Acz88] Peter Aczel. *Non-well-founded Sets*. Center for the Study of Language and Information Publication Lecture Notes. Cambridge University Press, 1988. (Cited on page 11.)
- [AFV01] Luca Aceto, Wan Fokkink, and Chris Verhoef. Structural operational semantics. In *Handbook of Process Algebra*, pages 197–292. Elsevier Science, 2001. (Cited on pages 9 and 14.)
- [AGJJ12] Robert Atkey, Neil Ghani, Bart Jacobs, and Patricia Johann. Fibrational induction meets effects. In Lars Birkedal, editor, *Foundations of Software Science and Computational Structures - 15th International Conference, FoSSaCS 2012, proceedings*, volume 7213 of *Lecture Notes in Computer Science*, pages 42–57. Springer, 2012. (Cited on page 52.)
- [AKV00] Jiří Adámek, Václav Koubek, and Jiří Velebil. A duality between infinitary varieties and algebraic theories. *Commentationes Mathematicae Universitatis Carolinae*, 41(3):529–542, 2000. (Cited on pages 86 and 143.)
- [AM89] Peter Aczel and Nax Mendler. A final coalgebra theorem. In *Category Theory and Computer Science, 1989, proceedings*, volume 389 of *LNCS*, pages 357–365. Springer, 1989. (Cited on pages 11, 46, 79, and 84.)
- [APTS13] Andreas Abel, Brigitte Pientka, David Thibodeau, and Anton Setzer. Copatterns: programming infinite structures by observations. In Giacobazzi and Cousot [GC13], pages 27–38. (Cited on page 9.)

- [Awo10] Steve Awodey. *Category Theory*. Oxford Logic Guides. OUP Oxford, 2010. (Cited on page 41.)
- [Bar03] Falk Bartels. Generalised coinduction. *Mathematical Structures in Computer Science*, 13(2):321–348, 2003. (Cited on page 93.)
- [Bar04] Falk Bartels. *On generalised coinduction and probabilistic specification formats*. PhD thesis, CWI, Amsterdam, April 2004. (Cited on pages 14, 15, 16, 41, 60, 62, 64, 65, 82, 117, and 121.)
- [BBB<sup>+</sup>12] Filippo Bonchi, Marcello Bonsangue, Michele Boreale, Jan Rutten, and Alexandra Silva. A coalgebraic perspective on linear weighted automata. *Information and Computation*, 211:77–105, 2012. (Cited on pages 44, 46, 48, 63, 68, 84, and 87.)
- [BH98] Michael Brandt and Fritz Henglein. Coinductive axiomatization of recursive type equality and subtyping. *Fundamenta Informaticae*, 33(4):309–338, 1998. (Cited on page 9.)
- [BHKR13] Marcello Bonsangue, Helle Hvid Hansen, Alexander Kurz, and Jurriiaan Rot. Presenting distributive laws. In Reiko Heckel and Stefan Milius, editors, *CALCO*, volume 8089 of *Lecture Notes in Computer Science*, pages 95–109. Springer, 2013. (Cited on page 18.)
- [BHKR15] Marcello Bonsangue, Helle Hvid Hansen, Alexander Kurz, and Jurriiaan Rot. Presenting distributive laws. *Logical Methods in Computer Science*, 11(3), 2015. (Cited on page 18.)
- [BIM95] Bard Bloom, Sorin Istrail, and Albert Meyer. Bisimulation can’t be traced. *Journal of the ACM*, 42(1):232–268, 1995. (Cited on pages 14 and 64.)
- [BK01] Peter Buchholz and Peter Kemper. Quantifying the dynamic behavior of process algebras. In Luca de Alfaro and Stephen Gilmore, editors, *PAPM-PROBMIV*, volume 2165 of *Lecture Notes in Computer Science*, pages 184–199. Springer, 2001. (Cited on pages 87 and 132.)
- [BM02] Maria Grazia Buscemi and Ugo Montanari. A first order coalgebraic model of pi-calculus early observational equivalence. In Lubos Brim, Petr Jancar, Mojmir Kretínský, and Antonín Kucera, editors, *CONCUR 2002 - Concurrency Theory, 13th International Conference, proceedings*, volume 2421 of *Lecture Notes in Computer Science*, pages 449–465. Springer, 2002. (Cited on page 139.)
- [BP12] Thomas Braibant and Damien Pous. Deciding kleene algebras in coq. *Logical Methods in Computer Science*, 8(1), 2012. (Cited on page 38.)
- [BP13] Filippo Bonchi and Damien Pous. Checking NFA equivalence with bisimulations up to congruence. In Giacobazzi and Cousot [GC13], pages 457–468. (Cited on pages 9, 13, 38, 70, and 73.)

- [BP15] Filippo Bonchi and Damien Pous. Hacking nondeterminism with induction and coinduction. *Communications of the ACM*, 58(2):87–95, 2015. (Cited on page 13.)
- [BPPR14] Filippo Bonchi, Daniela Petrisan, Damien Pous, and Jurriaan Rot. Coinduction up-to in a fibrational setting. In Thomas Henzinger and Dale Miller, editors, *Joint Meeting of the Twenty-Third EACSL Annual Conference on Computer Science Logic (CSL) and the Twenty-Ninth Annual ACM/IEEE Symposium on Logic in Computer Science (LICS), CSL-LICS 2014, proceedings*, page 20. ACM, 2014. (Cited on pages 17, 18, and 117.)
- [BPT15] Jasmin Christian Blanchette, Andrei Popescu, and Dmitriy Traytel. Witnessing (co)datatypes. In Jan Vitek, editor, *Programming Languages and Systems - 24th European Symposium on Programming, ESOP 2015, Proceedings*, volume 9032 of *Lecture Notes in Computer Science*, pages 359–382. Springer, 2015. (Cited on page 9.)
- [Brz64] Janusz Brzozowski. Derivatives of regular expressions. *Journal of the ACM*, 11(4):481–494, 1964. (Cited on pages 21, 22, and 30.)
- [BW05] Michael Barr and Charles Wells. Toposes, theories, and triples. Reprints in *Theory and Applications of Categories*, No. 12, 2005. Available at <http://www.tac.mta.ca/tac/reprints/articles/12/tr12abs.html>. (Cited on pages 41, 85, and 143.)
- [CHM02] Andrea Corradini, Reiko Heckel, and Ugo Montanari. Compositional SOS and beyond: a coalgebraic view of open systems. *Theoretical Computer Science*, 280(1-2):163–192, 2002. (Cited on page 139.)
- [Con71] John Conway. *Regular Algebra and Finite Machines*. Chapman and Hall, 1971. (Cited on pages 21 and 22.)
- [CS11] Thierry Coquand and Vincent Siles. A decision procedure for regular expression equivalence in type theory. In Jean-Pierre Jouannaud and Zhong Shao, editors, *Certified Programs and Proofs - First International Conference, CPP 2011, proceedings*, volume 7086 of *Lecture Notes in Computer Science*, pages 119–134. Springer, 2011. (Cited on pages 19 and 38.)
- [DK09] Manfred Droste and Werner Kuich. Semirings and formal power series. In *Handbook of Weighted Automata*, pages 3–28. Springer, 2009. (Cited on page 122.)
- [EHB13] Jörg Endrullis, Dimitri Hendriks, and Martin Bodin. Circular coinduction in Coq using bisimulation-up-to techniques. In Sandrine Blazy, Christine Paulin-Mohring, and David Pichardie, editors, *Interactive Theorem Proving - 4th International Conference, ITP 2013, proceedings*,

- volume 7998 of *Lecture Notes in Computer Science*, pages 354–369. Springer, 2013. (Cited on pages 13 and 38.)
- [FS10] Marcelo Fiore and Sam Staton. Positive structural operational semantics and monotone distributive laws. In *Coalgebraic Methods in Computer Science - 10th International Workshop, CMCS 2012, Short Contributions*, page 8, 2010. (Cited on pages 116 and 123.)
- [FS12] Simon Foster and Georg Struth. Automated analysis of regular algebra. In Bernhard Gramlich, Dale Miller, and Uli Sattler, editors, *Automated Reasoning - 6th International Joint Conference, IJCAR 2012, proceedings*, volume 7364 of *Lecture Notes in Computer Science*, pages 271–285. Springer, 2012. (Cited on page 25.)
- [GC13] Roberto Giacobazzi and Radhia Cousot, editors. *The 40th Annual ACM SIGPLAN-SIGACT Symposium on Principles of Programming Languages, POPL 2013, proceedings*. ACM, 2013. (Cited on pages 161, 162, and 165.)
- [GJF13] Neil Ghani, Patricia Johann, and Clément Fumex. Indexed induction and coinduction, fibrationally. *Logical Methods in Computer Science*, 9(3), 2013. (Cited on page 52.)
- [GR62] Seymour Ginsburg and H. Gordon Rice. Two families of languages related to ALGOL. *Journal of the ACM*, 9(3):350–371, 1962. (Cited on page 26.)
- [Gra05] Clemens Grabmayer. Using proofs by coinduction to find "traditional" proofs. In José Fiadeiro, Neil Harman, Markus Roggenbach, and Jan Rutten, editors, *Algebra and Coalgebra in Computer Science: First International Conference, CALCO 2005, proceedings*, volume 3629 of *Lecture Notes in Computer Science*, pages 175–193. Springer, 2005. (Cited on page 38.)
- [GS00] H. Peter Gumm and Tobias Schröder. Coalgebraic structure from weak limit preserving functors. *Electronic Notes Theoretical Computer Science*, 33:111–131, 2000. (Cited on page 80.)
- [GS01] H. Peter Gumm and Tobias Schröder. Monoid-labeled transition systems. *Electronic Notes Theoretical Computer Science*, 44(1):185–204, 2001. (Cited on pages 48, 68, and 84.)
- [HCKJ13] Ichiro Hasuo, Kenta Cho, Toshiki Kataoka, and Bart Jacobs. Coinductive predicates and final sequences in a fibration. *Electronic Notes Theoretical Computer Science*, 298:197–214, 2013. (Cited on pages 12, 41, 51, 52, and 56.)

- [HJ97] Ulrich Hensel and Bart Jacobs. Proof principles for datatypes with iterated recursion. In Eugenio Moggi and Giuseppe Rosolini, editors, *Category Theory and Computer Science, 7th International Conference, CTCS 1997, Proceedings*, volume 1290 of *Lecture Notes in Computer Science*, pages 220–241. Springer, 1997. (Cited on page 9.)
- [HJ98] Claudio Hermida and Bart Jacobs. Structural induction and coinduction in a fibrational setting. *Information and Computation*, 145(2):107–152, 1998. (Cited on pages 12, 41, 50, 52, 56, and 104.)
- [HJ04] Jesse Hughes and Bart Jacobs. Simulations in coalgebra. *Theoretical Computer Science*, 327(1-2):71–108, 2004. (Cited on pages 92, 113, 114, and 115.)
- [HK71] John Hopcroft and Richard Karp. A linear algorithm for testing equivalence of finite automata. Technical Report 114, Cornell University, December 1971. (Cited on page 70.)
- [HK11] Helle Hvid Hansen and Bartek Klin. Pointwise extensions of gsos-defined operations. *Mathematical Structures in Computer Science*, 21(2):321–361, 2011. (Cited on page 141.)
- [HKP09] Helle Hvid Hansen, Clemens Kupke, and Eric Pacuit. Neighbourhood structures: Bisimilarity and basic model theory. *Logical Methods in Computer Science*, 5(2), 2009. (Cited on page 68.)
- [HKR14] Helle Hvid Hansen, Clemens Kupke, and Jan Rutten. Stream differential equations: Specification formats and solution methods. Technical Report No. FM-1404, CWI, 2014. (Cited on pages 11, 14, 26, 27, 32, 38, 45, 47, and 65.)
- [HMSW11] Tony Hoare, Bernhard Möller, Georg Struth, and Ian Wehrman. Concurrent kleene algebra and its foundations. *Journal of Logic and Algebraic Programming*, 80(6):266–296, 2011. (Cited on page 36.)
- [HN11] Fritz Henglein and Lasse Nielsen. Regular expression containment: coinductive axiomatization and computational interpretation. In Thomas Ball and Mooly Sagiv, editors, *38th ACM SIGPLAN-SIGACT Symposium on Principles of Programming Languages, POPL 2011, proceedings*, pages 385–398. ACM, 2011. (Cited on page 38.)
- [HNDV13] Chung-Kil Hur, Georg Neis, Derek Dreyer, and Viktor Vafeiadis. The power of parameterization in coinductive proof. In Giacobazzi and Cousot [GC13], pages 193–206. (Cited on page 9.)
- [HR15] Thomas Henzinger and Jean-François Raskin. The equivalence problem for finite automata: technical perspective. *Communications of the ACM*, 58(2):86, 2015. (Cited on page 38.)

- [HU79] John Hopcroft and Jeffrey Ullman. *Introduction to Automata Theory, Languages and Computation*. Addison-Wesley, 1979. (Cited on page 19.)
- [Jac99] Bart Jacobs. *Categorical Logic and Type Theory*. Elsevier, 1999. (Cited on pages 52, 53, 54, 98, and 99.)
- [Jac06a] Bart Jacobs. A bialgebraic review of deterministic automata, regular expressions and languages. In Kokichi Futatsugi, Jean-Pierre Jouannaud, and José Meseguer, editors, *Essays Dedicated to Joseph A. Goguen*, volume 4060 of *LNCS*, pages 375–404. Springer, 2006. (Cited on page 9.)
- [Jac06b] Bart Jacobs. Distributive laws for the coinductive solution of recursive equations. *Information and Computation*, 204(4):561–587, 2006. (Cited on pages 14, 15, 62, 139, and 141.)
- [Jac12] Bart Jacobs. Introduction to coalgebra. Towards mathematics of states and observations, 2012. Draft. (Cited on pages 12, 41, 50, 51, 103, and 149.)
- [JNRS11] Bart Jacobs, Milad Niqui, Jan Rutten, and Alexandra Silva. Preface. *Theoretical Computer Science*, 412(38):4967–4968, 2011. (Cited on page 12.)
- [Joh75] Peter Johnstone. Adjoint lifting theorems for categories of algebras. *Bulletin of the London Mathematical Society*, 7:294–297, 1975. (Cited on page 62.)
- [JR12] Bart Jacobs and Jan Rutten. An introduction to (co)algebras and (co)induction. In *Advanced Topics in Bisimulation and Coinduction* [SR12], pages 38–99. (Cited on pages 11, 41, and 43.)
- [JSS12] Bart Jacobs, Alexandra Silva, and Ana Sokolova. Trace semantics via determinization. In Dirk Pattinson and Lutz Schröder, editors, *Coalgebraic Methods in Computer Science - 11th International Workshop, CMCS 2012, Revised Selected Papers*, volume 7399 of *Lecture Notes in Computer Science*, pages 109–129. Springer, 2012. (Cited on pages 14, 46, 60, 62, and 63.)
- [Kel80] Max Kelly. A unified treatment of transfinite constructions for free algebras, free monoids, colimits, associated sheaves, and so on. *Bulletin of the Australian Mathematical Society*, 22:1–84, 1980. (Cited on page 145.)
- [KKV12] Clemens Kupke, Alexander Kurz, and Yde Venema. Completeness for the coalgebraic cover modality. *Logical Methods in Computer Science*, 8(3), 2012. (Cited on page 51.)

- [Kli04] Bartek Klin. Adding recursive constructs to bialgebraic semantics. *Journal of Logic and Algebraic Programming*, 60-61:259–286, 2004. (Cited on pages 16 and 139.)
- [Kli07] Bartek Klin. Bialgebraic methods in structural operational semantics: Invited talk. *Electronic Notes Theoretical Computer Science*, 175(1):33–43, 2007. (Cited on pages 15 and 121.)
- [Kli09] Bartek Klin. Structural operational semantics for weighted transition systems. In Jens Palsberg, editor, *Semantics and Algebraic Specification, Essays Dedicated to Peter D. Mosses on the Occasion of His 60th Birthday*, volume 5700 of *Lecture Notes in Computer Science*, pages 121–139. Springer, 2009. (Cited on pages 14, 48, 68, and 84.)
- [Kli11] Bartek Klin. Bialgebras for structural operational semantics: An introduction. *Theoretical Computer Science*, 412(38):5043–5069, 2011. (Cited on pages 14, 41, 60, 61, 63, 64, 65, 132, 139, and 156.)
- [KN12] Alexander Krauss and Tobias Nipkow. Proof pearl: Regular expression equivalence and relation algebra. *Journal of Automated Reasoning*, 49(1):95–106, 2012. (Cited on pages 19 and 38.)
- [KN14] Bartek Klin and Beata Nachyla. Distributive laws and decidable properties of SOS specifications. In Johannes Borgström and Silvia Crafa, editors, *Combined 21st International Workshop on Expressiveness in Concurrency and 11th Workshop on Structural Operational Semantics, EXPRESS/SOS 2014, proceedings*, volume 160 of *EPTCS*, pages 79–93, 2014. (Cited on page 139.)
- [KNR11] Clemens Kupke, Milad Niqui, and Jan Rutten. Stream differential equations: concrete formats for coinductive definitions. Technical Report No. RR-11-10, Oxford University, 2011. (Cited on pages 27 and 32.)
- [Koz90] Dexter Kozen. On Kleene algebras and closed semirings. In Branislav Rován, editor, *MFCS*, volume 452 of *Lecture Notes in Computer Science*, pages 26–47. Springer, 1990. (Cited on page 26.)
- [KS14] Dexter Kozen and Alexandra Silva. Practical coinduction. *To appear in Mathematical Structures in Computer Science*, 2014. (Cited on page 9.)
- [Lan98] Saunders Mac Lane. *Categories for the Working Mathematician*. Graduate Texts in Mathematics. Springer New York, 1998. (Cited on pages 41 and 98.)
- [Len98] Marina Lenisa. *Themes in Final Semantics*. PhD thesis, Università di Pisa-Udine, 1998. (Cited on page 41.)

- [Len99] Marina Lenisa. From set-theoretic coinduction to coalgebraic coinduction: some results, some problems. *Electronic Notes Theoretical Computer Science*, 19:2–22, 1999. (Cited on pages 15, 16, and 117.)
- [LGCR09] Dorel Lucanu, Eugen-Ioan Goriac, Georgiana Caltais, and Grigore Rosu. CIRC: A behavioral verification tool based on circular coinduction. In Alexander Kurz, Marina Lenisa, and Andrzej Tarlecki, editors, *Algebra and Coalgebra in Computer Science, Third International Conference, CALCO 2009, proceedings*, volume 5728 of *Lecture Notes in Computer Science*, pages 433–442. Springer, 2009. (Cited on pages 9, 19, and 38.)
- [LLYL14] Lingyun Luo, Xinxin Liu, Xiaohua Yang, and Zhiming Liu. Up-to technique for product functor. *Journal of Computational Information Systems*, 10(22):9597–9607, 2014. (Cited on page 94.)
- [LPW00] Marina Lenisa, John Power, and Hiroshi Watanabe. Distributivity for endofunctors, pointed and co-pointed endofunctors, monads and comonads. *Electronic Notes Theoretical Computer Science*, 33:230–260, 2000. (Cited on pages 15, 93, and 117.)
- [LPW04] Marina Lenisa, John Power, and Hiroshi Watanabe. Category theory for operational semantics. *Theoretical Computer Science*, 327(1-2):135–154, 2004. (Cited on pages 16, 64, 139, and 160.)
- [Luo06] Lingyun Luo. An effective coalgebraic bisimulation proof method. *Electronic Notes Theoretical Computer Science*, 164(1):105–119, 2006. (Cited on pages 16 and 117.)
- [Mil80] Robin Milner. *A Calculus of Communicating Systems*, volume 92 of *LNCS*. Springer, 1980. (Cited on pages 10 and 47.)
- [Mil83] Robin Milner. Calculi for synchrony and asynchrony. *Theoretical Computer Science*, 25:267–310, 1983. (Cited on pages 13, 15, 39, 67, and 71.)
- [Mil89] Robin Milner. *Communication and concurrency*. PHI Series in computer science. Prentice Hall, 1989. (Cited on pages 9 and 15.)
- [Mil92] Robin Milner. Functions as processes. *Mathematical Structures in Computer Science*, 2(2):119–141, 1992. (Cited on page 120.)
- [Mis15] Michael Mislove. Semantics column. *SIGLOG News*, 2(2), 2015. (Cited on page 12.)
- [MM07] Ernie Manes and Philip Mulry. Monad compositions I: General constructions and recursive distributive laws. *Theory and Applications of Categories*, 18(7):172–208, 2007. (Cited on pages 16, 152, and 160.)

- [MMS13] Stefan Milius, Lawrence S. Moss, and Daniel Schwencke. Abstract gsos rules and a modular treatment of recursive definitions. *Logical Methods in Computer Science*, 9(3:28):52 pp., 2013. (Cited on pages 14 and 139.)
- [MPdS12] Nelma Moreira, David Pereira, and Simão de Sousa. Deciding regular expressions (in-)equivalence in Coq. In Wolfram Kahl and Timothy Griffin, editors, *Relational and Algebraic Methods in Computer Science - 13th International Conference, RAMiCS 2012, proceedings*, volume 7560 of *Lecture Notes in Computer Science*, pages 98–113. Springer, 2012. (Cited on page 38.)
- [MR05] Mohammad Reza Mousavi and Michel Reniers. Congruence for structural congruences. In Sassone [Sas05], pages 47–62. (Cited on pages 15, 16, 120, 133, 134, 135, and 138.)
- [NR09] Milad Niqui and Jan Rutten. Coinductive predicates as final coalgebras. In *6th Workshop on Fixed Points in Computer Science, FICS 2009, proceedings*, pages 79–85, 2009. (Cited on page 51.)
- [NR11] Milad Niqui and Jan Rutten. A proof of moessner’s theorem by coinduction. *Higher-Order and Symbolic Computation*, 24(3):191–206, 2011. (Cited on pages 10 and 13.)
- [NT14] Tobias Nipkow and Dmitriy Traytel. Unified decision procedures for regular expression equivalence. *Archive of Formal Proofs*, 2014, 2014. (Cited on page 38.)
- [Okh13] Alexander Okhotin. Conjunctive and boolean grammars: The true general case of the context-free grammars. *Computer Science Review*, 9:27–59, 2013. (Cited on page 30.)
- [Par81] David Park. Concurrency and automata on infinite sequences. In Peter Deussen, editor, *Theoretical Computer Science*, volume 104 of *LNCS*, pages 167–183. Springer, 1981. (Cited on pages 9, 10, 20, and 47.)
- [Plo01] Gordon Plotkin. Bialgebraic semantics and recursion (extended abstract). *Electronic Notes Theoretical Computer Science*, 44(1):285–288, 2001. (Cited on pages 16 and 139.)
- [Pou07] Damien Pous. Complete lattices and up-to techniques. In Zhong Shao, editor, *Programming Languages and Systems, 5th Asian Symposium, APLAS 2007, proceedings*, volume 4807 of *Lecture Notes in Computer Science*, pages 351–366. Springer, 2007. (Cited on pages 13, 15, 67, and 75.)
- [PS12] Damien Pous and Davide Sangiorgi. Enhancements of the bisimulation proof method. In *Advanced Topics in Bisimulation and Coinduction*

- [SR12], pages 233–289. (Cited on pages 13, 15, 27, 67, 68, 72, 75, 81, 82, 83, 119, 120, and 139.)
- [PW02] John Power and Hiroshi Watanabe. Combining a monad and a comonad. *Theoretical Computer Science*, 280(1-2):137–162, 2002. (Cited on page 148.)
- [RB14] Jurriaan Rot and Marcello Bonsangue. Combining bialgebraic semantics and equations. In Anca Muscholl, editor, *Foundations of Software Science and Computation Structures - 17th International Conference, FoSSaCS 2014, Proceedings*, volume 8412 of *Lecture Notes in Computer Science*, pages 381–395. Springer, 2014. (Cited on pages 17, 18, and 122.)
- [RB15] Jurriaan Rot and Marcello Bonsangue. Structural congruence for bialgebraic semantics. *Submitted*, 2015. (Cited on pages 17 and 83.)
- [RBB<sup>+</sup>15] Jurriaan Rot, Filippo Bonchi, Marcello Bonsangue, Damien Pous, Jan Rutten, and Alexandra Silva. Enhanced coalgebraic bisimulation. *To appear in Mathematical Structures in Computer Science*, 2015. (Cited on pages 17, 18, and 80.)
- [RBR13a] Jurriaan Rot, Marcello Bonsangue, and Jan Rutten. Coalgebraic bisimulation-up-to. In Peter van Emde Boas, Frans Groen, Giuseppe Italiano, Jerzy Nawrocki, and Harald Sack, editors, *39th International Conference on Current Trends in Theory and Practice of Computer Science, SOFSEM 2013, proceedings*, volume 7741 of *Lecture Notes in Computer Science*, pages 369–381. Springer, 2013. (Cited on pages 17 and 18.)
- [RBR13b] Jurriaan Rot, Marcello Bonsangue, and Jan Rutten. Coinductive proof techniques for language equivalence. In Adrian Horia Dediu, Carlos Martín-Vide, and Bianca Truthe, editors, *Language and Automata Theory and Applications - 7th International Conference, LATA 2013, proceedings*, volume 7810 of *Lecture Notes in Computer Science*, pages 480–492. Springer, 2013. (Cited on pages 16 and 18.)
- [RBR15] Jurriaan Rot, Marcello Bonsangue, and Jan Rutten. Proving language inclusion and equivalence by coinduction. *To appear in Information and Computation*, 2015. (Cited on pages 16 and 18.)
- [RT93] Jan Rutten and Daniele Turi. Initial algebra and final coalgebra semantics for concurrency. In Jaco de Bakker, Willem de Roever, and Grzegorz Rozenberg, editors, *A Decade of Concurrency, Reflections and Perspectives, REX School/Symposium, 1993, Proceedings*, volume 803 of *Lecture Notes in Computer Science*, pages 530–582. Springer, 1993. (Cited on page 14.)

- [Rut98a] Jan Rutten. Automata and coinduction (an exercise in coalgebra). In Davide Sangiorgi and Robert de Simone, editors, *CONCUR 1998: Concurrency Theory, 9th International Conference, proceedings*, volume 1466 of *Lecture Notes in Computer Science*, pages 194–218. Springer, 1998. (Cited on pages 9, 13, 19, 21, 22, 26, 37, and 39.)
- [Rut98b] Jan Rutten. Relators and metric bisimulations. *Electronic Notes Theoretical Computer Science*, 11:252–258, 1998. (Cited on page 50.)
- [Rut00] Jan Rutten. Universal coalgebra: a theory of systems. *Theoretical Computer Science*, 249(1):3–80, 2000. (Cited on pages 11, 41, 43, 46, 47, 78, 79, 80, 84, and 138.)
- [Rut03] Jan Rutten. Behavioural differential equations: a coinductive calculus of streams, automata, and power series. *Theoretical Computer Science*, 308(1-3):1–53, 2003. (Cited on pages 9, 10, 11, 19, 26, 28, 45, 47, and 75.)
- [Rut05] Jan Rutten. A coinductive calculus of streams. *Mathematical Structures in Computer Science*, 15(1):93–147, 2005. (Cited on page 13.)
- [San98] Davide Sangiorgi. On the bisimulation proof method. *Mathematical Structures in Computer Science*, 8(5):447–479, October 1998. (Cited on pages 13, 15, 67, and 117.)
- [San12a] Davide Sangiorgi. *An introduction to Bisimulation and Coinduction*. Cambridge University Press, 2012. (Cited on pages 9, 12, 48, 49, 127, and 132.)
- [San12b] Davide Sangiorgi. Origins of bisimulation and coinduction. In *Advanced Topics in Bisimulation and Coinduction* [SR12], pages 1–37. (Cited on page 20.)
- [Sas05] Vladimiro Sassone, editor. *Foundations of Software Science and Computational Structures, 8th International Conference, FoSSaCS 2005, proceedings*, volume 3441 of *Lecture Notes in Computer Science*. Springer, 2005. (Cited on pages 169 and 172.)
- [SBBR10] Alexandra Silva, Filippo Bonchi, Marcello Bonsangue, and Jan Rutten. Generalizing the powerset construction, coalgebraically. In Kamal Lodaya and Meena Mahajan, editors, *IARCS Annual Conference on Foundations of Software Technology and Theoretical Computer Science, FSTTCS 2010, Proceedings*, volume 8 of *LIPICs*, pages 272–283. Schloss Dagstuhl - Leibniz-Zentrum für Informatik, 2010. (Cited on pages 13 and 14.)
- [SBBR13] Alexandra Silva, Filippo Bonchi, Marcello Bonsangue, and Jan Rutten. Generalizing determinization from automata to coalgebras. *Logical*

- Methods in Computer Science*, 9(1), 2013. (Cited on pages 15, 46, 62, and 141.)
- [Sch05] Lutz Schröder. Expressivity of coalgebraic modal logic: The limits and beyond. In Sassone [Sas05], pages 440–454. (Cited on page 98.)
- [Sil15] Alexandra Silva. A short introduction to the coalgebraic method. *SIGLOG News*, 2(2), 2015. (Cited on page 12.)
- [SR12] Davide Sangiorgi and Jan Rutten. *Advanced Topics in Bisimulation and Coinduction*. Cambridge University Press, 2012. (Cited on pages 9, 166, 170, and 171.)
- [Sta11] Sam Staton. Relating coalgebraic notions of bisimulation. *Logical Methods in Computer Science*, 7(1), 2011. (Cited on page 50.)
- [SW01] Davide Sangiorgi and David Walker. *The Pi-Calculus - a theory of mobile processes*. Cambridge University Press, 2001. (Cited on page 119.)
- [TP97] Daniele Turi and Gordon Plotkin. Towards a mathematical operational semantics. In *12th Annual IEEE Symposium on Logic in Computer Science, 1997, proceedings*, pages 280–291. IEEE Computer Society, 1997. (Cited on pages 9, 14, 26, 41, 60, 62, 63, 65, and 82.)
- [Trn80] Vera Trnková. General theory of relational automata. *Fundamenta Informaticae*, 3(2):189–234, 1980. (Cited on page 51.)
- [Tur96] Daniele Turi. *Functorial Operational Semantics and its Denotational Dual*. PhD thesis, Free University, Amsterdam, June 1996. (Cited on page 41.)
- [Wat02] Hiroshi Watanabe. Well-behaved translations between structural operational semantics. *Electronic Notes Theoretical Computer Science*, 65(1):337–357, 2002. (Cited on pages 16, 148, and 160.)
- [WBR13] Joost Winter, Marcello Bonsangue, and Jan Rutten. Coalgebraic characterizations of context-free languages. *Logical Methods in Computer Science*, 9(3), 2013. (Cited on pages 15, 16, 142, 155, 158, and 159.)
- [Win14] Joost Winter. *Coalgebraic Characterizations of Automata-theoretic Classes*. PhD thesis, Radboud Universiteit Nijmegen, 2014. (Cited on page 155.)
- [Win15] Joost Winter. A completeness result for finite  $\lambda$ -bisimulations. In Andrew Pitts, editor, *Foundations of Software Science and Computation Structures - 18th International Conference, FoSSaCS 2015, Proceedings*, volume 9034 of *Lecture Notes in Computer Science*, pages 117–132. Springer, 2015. (Cited on pages 13 and 73.)

- [ZLL<sup>+</sup>10] Xiaocong Zhou, Yongji Li, Wenjun Li, Hai-yan Qiao, and Zhongmei Shu. Bisimulation proof methods in a path-based specification language for polynomial coalgebras. In Kazunori Ueda, editor, *Programming Languages and Systems - 8th Asian Symposium, APLAS 2010, proceedings*, volume 6461 of *Lecture Notes in Computer Science*, pages 239–254. Springer, 2010. (Cited on pages 16 and 117.)

# Index

- $(\rho, E)$ -model, 133
- $(\rho, \Delta)$ -model, 124
- $F$ -invariant, 51
- $M(\rho)$ , 123
- $(\mathcal{T}, \mathcal{E})$ -Alg, 142
- $\mathcal{T}$ -Alg, 58
- Cat, 98
- $\text{Fib}(-)$ , 98
- Id, *see also* identity functor
- $\mathcal{M}$ , 42
- Pre, 114
- Rel, 54
- $\text{Rel}(B)$ , *see also* relation lifting
- Set, 41
- $\Sigma^*$ , *see also* free monad
- $\hat{\alpha}$ , 60
- $T$ -alg, 58
- be, 84
- $\text{bhv}_\delta$ , 96
- bis, 70
- $\text{b}_\delta$ , 50, 56
- $\bullet$ , 77, 100
- $\text{cgr}_\alpha$ , 73
- CJSL, 122
- $B$ -coalg, 43
- cst, 76
- $\text{ctx}_\alpha$ , 71
- diag, 99
- $\coprod_f$ , *see also* direct image
- eq, 69
- $\rho^\dagger$ , 63
- inv, 99
- $\mathbb{G}$ , 125
- $\mathbb{M}$ , 123
- $\otimes$ , 98
- $\mathcal{P}$ , 42
- $\mathcal{P}_\omega$ , 42
- $\overline{B}_\delta$ , 95
- $\psi$ , 124
- rfl, 70
- slf, 101
- sym, 70
- $\theta$ , 133
- tra, 70, 100
- $\text{un}_S$ , 71
- $\varphi$ , 126
- $f$ -invariant, 49
- $f^*$ , *see also* reindexing
- cfsc, 134
- abstract GSOS, 63
  - monotone, 115, 123
- algebra, 58
- Arden's rule, 25, 36
- assignment rule, 123
- base category, 53
- BDE, *see also* behavioural differential equations
- behavioural differential equations, 26, 28, 45, 65
  - monotone, 35
- behavioural equivalence, 43
- bialgebra, 61
- bifibration, 53
- bisimilarity, *see also* bisimulation
- bisimilarity closure, 70
- bisimulation, 46
  - deterministic automata, 20

- bisimulation up-to, 68
  - bisimilarity, 71
  - congruence, 73
  - context, 71
  - equivalence, 69
  - languages, 24, 27
  - soundness, 69
  - union, 71
- Brzozowski, 21
- Cartesian lifting, 53
- causal function, 32
- coalgebra, 42
- coinduction, 43, 48
  - classical, 48
- coinductive extension, 43
- coinductive predicate, 49, 56
- compatible, 76
- compatible functor, 93
- complete lattice, 48
- congruence closure, 27, 73
  - regular expressions, 23
- contextual closure, 71, 101
  - monotone, 110
- copointed functor, 63
- DA, *see also* deterministic automata
- deterministic automata, 20
  - bisimulation, 20
  - simulation, 34, 50
- deterministic automaton, 44
- determinization, 46, 62
- diagonal relation, 42
- direct image, 42, 54
- distributive law, 60
  - monad over copointed functor, 63
  - monad over functor, 62
- divergence, 52, 111
- Eilenberg-Moore algebra, 58
- equal up to bisimilarity, 83
- equations, 132, 142
- equivalence closure, 69
- fibration, 52
- fibration map, 54
- fibre, 53
- fibred (co)products, 54
- final coalgebra, 43
- fixed point, 48
- free algebra, 59
- free monad, 60
- GSOS, 64
  - positive, 116
- homomorphism
  - algebra, 58
  - bialgebra, 61
  - coalgebra, 42
- identity functor, 42
- inductive extension, 58
- initial algebra, 58
- interpretation
  - language, 27
  - of  $\rho$  and  $\Delta$ , 124
- invariant, 56
- invariant up-to, 76, 92
- inverse image, 42
- kernel, 42
- labelled transition system, 43
- language, 20
  - derivative, 20
- lifting, 54, 62
- LTS, *see also* labelled transition system
- modality, 97
- monad, 58
- monad morphism, 59
- monotone function, 48
- Moore automaton, 44
- morphism of distributive laws, 148
- non-deterministic automaton, 44
- operational model, 64
- ordered functor, 114
  - CJSL, 122
  - stable, 115

- polynomial functor, 58
- post-fixed point, 48
- predicate bifibration, 54
- presentation
  - distributive law, 152
  - monad, 147
- preservation of equations, 149
- product
  - categories, 42
  - functors, 42
  - sets, 41
- progression, 68
- quotient monad, 145
- reflexive closure, 70
- reflexive coequalizer, 85
- regular epimorphism, 142
- reindexing, 53
- relation bifibration, 54
- relation lifting, 50
  - lax, 115
- replication, 119
- semiring, 42
- shuffle, 31, 45
- shuffle closure, 31
- shuffle inverse, 45
- signature, 27, 58
- simulation
  - coalgebras, 115
  - deterministic automata, 34, 50
  - transition systems, 115
- simulation up-to
  - languages, 35
- sound, 76, 92
- soundness, 69
- stream, 43
- stream system, 43
- symmetric closure, 70
- total category, 53
- transfinite induction, 127
- transitive closure, 70
- weighted automaton, 44
- weighted language inclusion, 108
- weighted transition system, 44, 122