# CURRICULUM VITÆ

SYLVAIN SCHMITZ

*February 15, 2019*

**date of birth:** June 1, 1980
**citizenship:** French
**homepage:** `http://www.lsv.fr/~schmitz/`

## 1. Research Topics

Logic in computer science; verification; complexity theory; formal languages

## 2. Academic Employment

**since 2008:** lecturer, École Normale Supérieure Paris-Saclay
**2018–2023:** member of Institut Universitaire de France
**2013–2015:** on partial leave at Inria Paris-Saclay, Dahu team
**2007–2008:** post-doctoral researcher, Inria Nancy Grand-Est, Talaris team
**2006–2007:** research assistant, Université de Nice - Sophia Antipolis
**2003–2006:** teaching assistant, Université de Nice - Sophia Antipolis

*Long Research Visits:*

**Apr.–Jul. 2017:** invited researcher, University of Warsaw, funded by the ERC Lipa
**Feb.–Jul. 2015:** invited professor, University of Warwick, funded by the Leverhulme Trust

## 3. Education

**2017:** Habilitation, École Normale Supérieure Paris-Saclay
**title:** *Algorithmic Complexity of Well-Quasi-Orders* [T1]
**date:** Nov. 27, 2017

**2007:** Ph.D. in Computer Science, Université de Nice - Sophia Antipolis
**title:** *Approximating Context-Free Grammars for Parsing and Verification* [T2]
**date:** Sep. 27, 2007
**supervisor:** Jacques Farré

**2003:** M.S. in Theoretical Computer Science, Université de Nice - Sophia Antipolis
**2003:** M.S. in Software Engineering, Université de Nice - Sophia Antipolis

## 4. Research Funding

*Main Research Projects:*

**2017–2020:** Participant of ANR BraVAS: *Ideal-based algorithms for VASSes and well-structured systems*
**website:** `http://bravas.labri.fr/`

**2015–2019:** Principal investigator of ANR prodaq: *Proof systems for data queries*
**website:** `http://projects.lsv.fr/prodaq/`

**2011–2014:** Participant of ANR ReacHard: *Taming hard reachability problems*
**website:** `http://www.lsv.fr/Projects/anr-reachard/`

## 5. Awards

- Best paper award at RTA-TLCA 2014 for [C13]
- ACM Computing Review's 21st Annual Best in Computing: Notable Books and Articles in Computing of 2016 for [J5]

## 6. Supervision

*PhD Students:*

**Anthony Lick:** since Sep. 2016. Joint supervision with David Baelde, funded by ANR prodaq. Topics: data logics, XPath, proof systems.

**Simon Halfon:** Sep. 2015–Aug. 2018. Joint supervision with Philippe Schnoebelen. Topics: well-quasi-orders, complexity, verification of infinite-state systems. Defended on June 29 2018.

*Master Students:*

**Aliaume Lopez:** Mar.–Jul. 2019. Joint supervision with Jean Goubault-Larrecq. Topics: data-centric dynamic systems and well-quasi-orders on relational structures.

**Balasubramanian Ayikudi Ramachandrakumar:** May–Jul. 2019. Joint supervision with Philippe Schnoebelen, funded by UMI ReLaX. Topic: powersets and antichains in well-quasi-orders.

**Anthony Lick:** Mar.–Jul. 2016. Joint supervision with David Baelde, funded by ANR prodaq. Topics: proof systems for logics on finite words.

**Simon Lunel:** Apr.–Jul. 2015. Joint supervision with David Baelde, funded by ANR prodaq. Topic: proof systems for data logics on finite data trees; see [C6].

**Jean-Baptiste Courtois:** Apr.–Aug. 2013. Topics: multi-dimensional energy games and simulation games on vector addition systems; see [C12].

**Prateek Karandikar:** June 2012. Topic: complexity of the Post Embedding Problem; see [C17].

**Michel Blockelet:** Feb.–Aug. 2010. Topic: model-checking the coverability graphs of vector addition systems; see [C20].

*Bachelor Students:*

**Ashwani Anand:** May–Jun. 2018. Joint supervision with Thomas Colcombet, funded by UMI ReLaX. Topic: polynomial vector addition systems with states.

**Killaru Manuj:** May–Jun. 2016. Joint supervision with Étienne Lozes, funded by ANR prodaq. Topic: separation logic on data words.

**Anudhyan Boral:** May–Jul. 2012. Topic: model-checking parse trees, with applications in computational linguistics and programming language design; see [C16].

## 7. Academic Activities

*Program Committees:*

- international conferences: NAACL-HLT 2019 (subcommittee on Theory and Formalisms), LICS 2018, Petri nets 2017, STACS 2017.
- international workshops: RP 2015 and 2012, CSLP 2012, LDTA 2012 and 2011, TAG+10 and TAG+9

*Steering Committees:* Member of the steering committee of the French working group on verification GT Vérif since 2014.

*Organising Committees:* Highlights 2014 (co-chair), GT-Vérif 2014, GT-Vérif 2013 (chair), and CIAA 2005.

*PhD Committees:*

- Michael Blondin, *Algorithmics and Complexity of Counter Machines*, Jun. 29, 2016, Université de Montréal et Université Paris-Saclay.
- Silvia Steila, *Terminating via Ramsey's Theorem*, Jan. 26 2016, Università degli studi di Torino (reviewer).
- Jérôme Kirman, *Mise au point d'un formalisme syntaxique de haut niveau pour le traitement automatique des langues*, Dec. 4, 2015, Université de Bordeaux.

- Bas Basten, *Ambiguity Detection for Programming Language Grammars*, Dec. 15, 2011, CWI, Amsterdam (reviewer).

*Hiring Committees:*

- lecturer positions at Université Paris-Diderot (2019, maths dpt.), École Polytechnique (2017), Université Paris-Est Marne-la-Vallée (2018, 2016, 2013), Université de Lorraine (2016), Université Bordeaux I (2012), Université Paris IV (2012)
- teaching positions in mathematics at ENS Paris-Saclay (2018, 2015, 2014, 2013).

*Evaluation Committees:* External reviewer for project proposals for ANR (France) in 2013, 2015, and 2016, for NCN (Poland) in 2018 and 2017, for FWF (Austria) in 2015, for NWO (Netherlands) in 2009.

## 8. Invited Talks at Workshops and Conferences

- invited talk at *12th Panhellenic Logic Symposium*,
- invited talk at *Complexity, Algorithms, Automata and Logic Meet* (CAALM 2019),
- invited talk at *6th Workshop on Quantitative Logics and Automata* (QuantLA 2018),
- invited tutorial at *13th Summer School on Modelling and Verification of Parallel Processes* (MOVEP 2018),
- invited talk at *20th International Workshop on Verification of Infinite-State Systems* (Infinity 2018, satellite of ICALP 2018),
- invited talk at Gregynog 71717 *Workshop on Vector Addition Systems*
- invited talk at *Workshop on Separation Problems* (satellite of ICALP 2017)
- invited talk at Dagstuhl Seminar 16031 *Well Quasi-Orders in Computer Science*,
- invited talk at *DIMAP Logic Day 2015*,
- invited talk at *4th Workshop on Automata, Concurrency and Timed Systems* (ACTS 2015),
- invited talk at *8th International Workshop on Reachability Problems* (RP 2014),
- invited tutorial at Dagstuhl Seminar 14141 *Reachability Problems for Infinite-State Systems*.

See `http://www.lsv.fr/~schmitz/talks` for my full list of talks.

## 9. Teaching

**Courses.** See `http://www.lsv.fr/~schmitz/teach` for my lecture notes, home assignments, exercise sheets, etc. Codes: L1/L2/L3: first, second, and third year of Bachelor; M1/M2: first and second years of Master; D: PhD students.

*At ENS Paris-Saclay:* note that students enter ENS Paris-Saclay directly in L3 or later.

- Programming and formal semantics (L3 CS), projects and labs: 2012; tutorials: 2017.
- Formal languages (L3 CS), lectures: 2016, 2017; tutorials: 2008, 2009, 2015.
- Computational complexity (L3 CS), tutorials: 2015.
- Software engineering (L3 CS), projects and labs: 2008.
- Verification (M1 CS), lectures: 2015; tutorials: 2008, 2009, 2010, 2011, 2012, 2013.
- Tree automata, techniques and applications (M1 CS), lectures: 2016, 2017, 2018.
- Logical and computational structures for linguistic modelling (M2 CS), lectures: 2010, 2011, 2013, 2014, 2015, 2016, 2017, 2018.
- Formal languages (M2 Maths), lectures and tutorials: 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017.
- Logic and rewriting (M2 Maths), lectures and tutorials: 2016, 2017, 2018.
- Searching and publishing on the web (D), lectures and labs: 2011, 2012, 2015, 2016.

*At Université de Nice - Sophia Antipolis:*

- Algorithmics and data structures (L1 CS), labs and tutorials: 2006.
- Algorithmics and Java programming, labs (L1 Elec. Eng.): 2003; labs and projects (L2 Elec. Eng.): 2004.
- Algorithmics and Pascal programming (L1 CS), labs: 2003.
- Algorithmics and C programming (L1 and L3 CS), labs: 2005.
- XML and text processing (L1 Eng.), lectures and labs: 2006.

- Unix (L2 Elec. Eng.), labs: 2004.
- Compilers (L3 CS), labs and tutorials: 2004.
- Compiling an object-oriented language (M1 CS), labs and tutorials: 2005.
- Parsing and natural language processing (M2 CS), lectures: 2005 and 2006.

*At Summer Schools:*

- Algorithmic aspects of wqo theory, ESSLLI 2012 and 2016, joint with Philippe Schnoebelen; see [L1].

**Administration.**

**Sep. 2015–Sept. 2018:** head of the first year of the Master of Computer Science at ENS Paris-Saclay

**Sep. 2009–Aug. 2013:** head of the Computer Science curriculum in the *préparation à l'agrégation de mathématiques* at ENS Paris-Saclay

## 10. Software Development

- ambiguity checking in GNU/Bison (2006–2007); see [W5; J9]
- grammar test suite generator (2008); see [F1; W4]
- tools for deterministic tree walking automata (2009); see [C25; J8]
- XPath parser and benchmarks (2016–2018); see [C1]

## 11. Publications

*Invited Papers:*

[I1] Leroux, J. and Schmitz, S., 2016. Ideal decompositions for vector addition systems. In *Proceedings of* **STACS 2016**, volume 47 of *Leibniz International Proceedings in Informatics*, article 1, 13 pages. LZI. doi:10.4230/LIPIcs.STACS.2016.1.

[I2] Schmitz, S., 2016. Automata column: The complexity of reachability in vector addition systems. ***ACM SIGLOG News***, 3(1):3–21. doi:10.1145/2893582.2893585.

[I3] Schmitz, S., 2014. Complexity bounds for ordinal-based termination. In *Proceedings of* **RP 2014**, volume 8762 of *Lecture Notes in Computer Science*, pages 1–19. Springer. doi:10.1007/978-3-319-11439-2_1.

[I4] Schmitz, S. and Schnoebelen, Ph., 2013. The power of well-structured systems. In *Proceedings of* **Concur 2013**, volume 8052 of *Lecture Notes in Computer Science*, pages 5–24. Springer. doi:10.1007/978-3-642-40184-8_2.

*Journal Papers:*

[J1] Lazić, R. and Schmitz, S., 2019. The ideal view on Rackoff's coverability technique. ***Information and Computation***. hal.inria.fr:hal-01176755. To appear.

[J2] Bérard, B., Haar, S., Schmitz, S., and Schwoon, S., 2018. The complexity of diagnosability and opacity verification for Petri nets. ***Fundamenta Informatica***, 161(4):317–349. doi:10.3233/FI-2018-1706.

[J3] Schmitz, S., 2016. Implicational relevance logic is 2-ExpTime-complete. ***Journal of Symbolic Logic***, 81(2):641–661. doi:10.1017/jsl.2015.7.

[J4] Chambart, P., Finkel, A., and Schmitz, S., 2016. Forward analysis and model checking for trace bounded WSTS. ***Theoretical Computer Science***, 637:1–29. doi:10.1016/j.tcs.2016.04.020.

[J5] Schmitz, S., 2016. Complexity hierarchies beyond Elementary. ***ACM Transactions on Computation Theory***, 8(1:3):1–36. doi:10.1145/2858784.

[J6] Lazić, R. and Schmitz, S., 2015. Non-elementary complexities for branching VASS, MELL, and extensions. ***ACM Transactions on Computational Logic***, 16(3:20):1–30. doi:10.1145/2733375.

[J7] Haase, C., Schmitz, S., and Schnoebelen, Ph., 2014. The power of priority channel systems. ***Logical Methods in Computer Science***, 10(4:4):1–39. doi:10.2168/LMCS-10(4:4)2014.

[J8] Héam, P.C., Nicaud, C., and Schmitz, S., 2010. Parametric random generation of deterministic tree automata. ***Theoretical Computer Science***, 411(38–39):3469–3480. doi:10.1016/j.tcs.2010.05.036.

[J9] Schmitz, S., 2010. An experimental ambiguity detection tool. ***Science of Computer Programming***, 75(1–2):71–84. doi:10.1016/j.scico.2009.07.002.

*Conference Papers:*

[C1] Baelde, D., Lick, A., and Schmitz, S., 2019. Decidable XPath fragments in the real world. In *Proceedings of* **PODS 2019**. ACM. hal.inria.fr:hal-01852475. To appear.

[C2] Baelde, D., Lick, A., and Schmitz, S., 2018. A hypersequent calculus with clusters for tense logic over ordinals. In *Proceedings of* **FSTTCS 2018**, *Leibniz International Proceedings in Informatics*, article 15, 19 pages. LZI. doi:10.4230/LIPIcs.FSTTCS.2018.15.

[C3] Baelde, D., Lick, A., and Schmitz, S., 2018. A hypersequent calculus with clusters for linear frames. In *Proceedings of* **AiML 2018**, volume 12 of *Advances in Modal Logic*, pages 36–55. College Publications. hal.inria.fr:hal-01756126.

[C4] Colcombet, Th., Jurdziński, M., Lazić, R., and Schmitz, S., 2017. Perfect half-space games. In *Proceedings of* **LICS 2017**. IEEE. doi:10.1109/LICS.2017.8005105.

[C5] Bérard, B., Haar, S., Schmitz, S., and Schwoon, S., 2017. The complexity of diagnosability and opacity verification for Petri nets. In *Proceedings of* **Petri Nets 2017**, volume 10258 of *Lecture Notes in Computer Science*, pages 200–220. Springer. doi:10.1007/978-3-319-57861-3_13. Superseded by [J2].

[C6] Baelde, D., Lunel, S., and Schmitz, S., 2016. A sequent calculus for a modal logic on finite data trees. In *Proceedings of* **CSL 2016**, volume 62 of *Leibniz International Proceedings in Informatics*, article 32, 16 pages. LZI. doi:10.4230/LIPIcs.CSL.2016.32.

[C7] Goubault-Larrecq, J. and Schmitz, S., 2016. Deciding piecewise testable separability for regular tree languages. In *Proceedings of* **ICALP 2016**, volume 55 of *Leibniz International Proceedings in Informatics*, article 97, 15 pages. LZI. doi:10.4230/LIPIcs.ICALP.2016.97.

[C8] Lazić, R. and Schmitz, S., 2016. The complexity of coverability in $\nu$-Petri nets. In *Proceedings of* **LICS 2016**, pages 467–476. ACM. doi:10.1145/2933575.2933593.

[C9] Hofman, P., Lasota, S., Lazić, R., Leroux, J., Schmitz, S., and Totzke, P., 2016. Coverability trees for Petri nets with unordered data. In *Proceedings of* **FoSSaCS 2016**, volume 9634 of *Lecture Notes in Computer Science*, pages 445–461. Springer. doi:10.1007/978-3-662-49630-5_26.

[C10] Jurdziński, M., Lazić, R., and Schmitz, S., 2015. Fixed-dimensional energy games are in pseudo-polynomial time. In *Proceedings of* **ICALP 2015**, volume 9135 of *Lecture Notes in Computer Science*, pages 260–272. Springer. doi:10.1007/978-3-662-47666-6_21.

[C11] Leroux, J. and Schmitz, S., 2015. Demystifying reachability in vector addition systems. In *Proceedings of* **LICS 2015**, pages 56–67. IEEE. doi:10.1109/LICS.2015.16.

[C12] Courtois, J.B. and Schmitz, S., 2014. Alternating vector addition systems with states. In *Proceedings of* **MFCS 2014**, volume 8634 of *Lecture Notes in Computer Science*, pages 220–231. Springer. doi:10.1007/978-3-662-44522-8_19.

[C13] Schmitz, S., 2014. Implicational relevance logic is 2-ExpTime-complete. In *Proceedings of* **RTA-TLCA 2014**, volume 8560 of *Lecture Notes in Computer Science*, pages 395–409. Springer. doi:10.1007/978-3-319-08918-8_27. Superseded by [J3].

[C14] Lazić, R. and Schmitz, S., 2014. Non-elementary complexities for branching VASS, MELL, and extensions. In *Proceedings of* **CSL-LICS 2014**, article 61, 10 pages. ACM. doi:10.1145/2603088.2603129. Superseded by [J6].

[C15] Haase, C., Schmitz, S., and Schnoebelen, Ph., 2013. The power of priority channel systems. In *Proceedings of* **Concur 2013**, volume 8052 of *Lecture Notes in Computer Science*, pages 319–333. Springer. doi:10.1007/978-3-642-40184-8_23. Superseded by [J7].

[C16] Boral, A. and Schmitz, S., 2013. Model checking parse trees. In *Proceedings of* **LICS 2013**, pages 153–162. IEEE Press. doi:10.1109/LICS.2013.21.

[C17] Karandikar, P. and Schmitz, S., 2013. The parametric ordinal-recursive complexity of Post embedding problems. In *Proceedings of* **FoSSaCS 2013**, volume 7794 of *Lecture Notes in Computer Science*, pages 273–288. Springer. doi:10.1007/978-3-642-37075-5_18.

[C18] Bertsch, E., Nederhof, M.J., and Schmitz, S., 2013. On LR parsing with selective delays. In *Proceedings of* **CC 2013**, volume 7791 of *Lecture Notes in Computer Science*, pages 244–263. Springer. doi:10.1007/978-3-642-37051-9_13.

[C19] Haddad, S., Schmitz, S., and Schnoebelen, Ph., 2012. The ordinal recursive complexity of timed-arc Petri nets, data nets, and other enriched nets. In *Proceedings of* **LICS 2012**, pages 355–364. IEEE Press. doi:10.1109/LICS.2012.46.

[C20] Blockelet, M. and Schmitz, S., 2011. Model-checking coverability graphs of vector addition systems. In *Proceedings of* **MFCS 2011**, volume 6907 of *Lecture Notes in Computer Science*, pages 108–119. Springer. doi:10.1007/978-3-642-22993-0_13.

[C21] Schmitz, S. and Schnoebelen, Ph., 2011. Multiply-recursive upper bounds with Higman's Lemma. In *Proceedings of* **ICALP 2011**, volume 6756 of *Lecture Notes in Computer Science*, pages 441–452. Springer. doi:10.1007/978-3-642-22012-8_35.

[C22] Figueira, D., Figueira, S., Schmitz, S., and Schnoebelen, Ph., 2011. Ackermannian and primitive-recursive bounds with Dickson's Lemma. In *Proceedings of* **LICS 2011**, pages 269–278. IEEE Press. doi:10.1109/LICS.2011.39.

[C23] Chambart, P., Finkel, A., and Schmitz, S., 2011. Forward analysis and model checking for trace bounded WSTS. In *Proceedings of* **Petri Nets 2011**, volume 6709 of *Lecture Notes in Computer Science*, pages 49–68. Springer. doi:10.1007/978-3-642-21834-7_4. Superseded by [J4].

[C24] Schmitz, S., 2010. On the computational complexity of dominance links in grammatical formalisms. In *Proceedings of* **ACL 2010**, pages 514–524. ACL Press. hal.archives-ouvertes.fr:hal-00482396.

[C25] Héam, P.C., Nicaud, C., and Schmitz, S., 2009. Random generation of deterministic tree (walking) automata. In *Proceedings of* **CIAA 2009**, volume 5642 of *Lecture Notes in Computer Science*, pages 115–124. Springer. doi:10.1007/978-3-642-02979-0_15. Superseded by [J8].

[C26] Schmitz, S., 2007. Conservative ambiguity detection in context-free grammars. In *Proceedings of* **ICALP 2007**, volume 4596 of *Lecture Notes in Computer Science*, pages 692–703. Springer. doi:10.1007/978-3-540-73420-8_60.

[C27] Schmitz, S., 2006. Noncanonical LALR(1) parsing. In *Proceedings of* **DLT 2006**, volume 4036 of *Lecture Notes in Computer Science*, pages 95–107. Springer. doi:10.1007/11779148_10.

[C28] Fortes Gálvez, J., Schmitz, S., and Farré, J., 2006. Shift-resolve parsing: Simple, linear time, unbounded lookahead. In *Proceedings of* **CIAA 2006**, volume 4094 of *Lecture Notes in Computer Science*, pages 253–264. Springer. doi:10.1007/11812128_24.

*Workshop Papers:*

[W1] Lazić, R. and Schmitz, S., 2015. The ideal view on Rackoff's coverability technique. In *Proceedings of* **RP 2015**, volume 9328 of *Lecture Notes in Computer Science*, pages 1–13. Springer. doi:10.1007/978-3-319-24537-9_8. Superseded by [J1].

[W2] Gardent, C., Parmentier, Y., Perrier, G., and Schmitz, S., 2014. Lexical disambiguation in LTAG using left context. In *Proceedings of* **LTC 2011**, volume 8387 of *Lecture Notes in Computer Science*, pages 67–79. Springer. doi:10.1007/978-3-319-08958-4_6.

[W3] Schmitz, S., 2011. A note on sequential rule-based POS tagging. In *Proceedings of* **FSMNLP 2011**, pages 83–87. ACL Press. hal.archives-ouvertes.fr:hal-00600260. Short paper.

[W4] Schmitz, S. and Le Roux, J., 2008. Feature unification in TAG derivation trees. In *Proceedings of* **TAG+9**, pages 141–148. arXiv:0804.4584[cs.CL].

[W5] Schmitz, S., 2008. An experimental ambiguity detection tool. In *Proceedings of* **LDTA 2007**, volume 203(2) of *Electronic Notes in Theoretical Computer Science*, pages 69–84. Elsevier Science Publishers. doi:10.1016/j.entcs.2008.03.045. Superseded by [J9].

*Book Chapters:*

[B1] Džamonja, M., Schmitz, S., and Schnoebelen, Ph., 2019. On ordinal invariants in well quasi orders and finite antichain orders. In *Well-Quasi Orders in Computation, Logic, Language and Reasoning, Trends in Logic*. Springer. arXiv:1711.00428[math.LO]. To appear.

*French Conference Papers:*

[F1] Schmitz, S. and Le Roux, J., 2008. Calculs d'unification sur les arbres de dérivation TAG. In *Proceedings of* **TALN 2008**, pages 320–329. hal.inria.fr:inria-00270922. French version of [W4].

*Theses:*

[T1] Schmitz, S., 2017. *Algorithmic Complexity of Well-Quasi-Orders.* Habilitation thesis, École Normale Supérieure Paris-Saclay. tel.archives-ouvertes.fr:tel-01663266.

[T2] Schmitz, S., 2007. *Approximating Context-Free Grammars for Parsing and Verification.* Ph.D. Thesis, Université de Nice - Sophia Antipolis. tel.archives-ouvertes.fr:tel-00271168.

*Research Reports:*

[R1] Schmitz, S., 2006. Modular syntax demands verification. Technical Report I3S/RR-2006-32-FR, Laboratoire I3S, Université de Nice - Sophia Antipolis & CNRS. http://www.i3s.unice.fr/~mh/RR/2006/RR-06.32-S.SCHMITZ.pdf.

*Lecture Notes:*

[L1] Schmitz, S. and Schnoebelen, Ph., 2012. Algorithmic aspects of wqo theory. cel.archives-ouvertes.fr:cel-00727025. Lecture notes, *ESSLLI 2012*, 108 pages.

[L2] Schmitz, S., 2018. Logique propositionnelle. cel.archives-ouvertes.fr:cel-01903823. Notes de révision pour l'agrégation, 37 pages.

[L3] Schmitz, S., 2018. Systèmes de preuve. cel.archives-ouvertes.fr:cel-01903833. Notes de révision pour l'agrégation, 42 pages.

*Submitted:*

[S1] Schmitz, S., 2019. The parametric complexity of lossy counter machines. Preprint. hal.archives-ouvertes.fr:hal-02020728.

[S2] Jančar, P. and Schmitz, S., 2019. Bisimulation equivalence of first-order grammars is ACKERMANN-complete. Preprint. arXiv:1901.07170[cs.LO].