Smart Contract Languages: A Multivocal Mapping Study Appendixes

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Contents

A APPENDIX. PAPERS IN THE FINAL DATASET

A.1 Selected papers of white literature

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Table 1. Selected primary studies

ID	Ref	Title	Author(s)	Venue
S01	[S1]	Distributed Electronic Rights in JavaScript	M.S. Miller, T. Van Cutsem, B. Tulloh	ESOP'13:1-20, 2013
S02	[S2]	eContractual choreography-language properties towards cross-organizational business collaboration	A. Norta, L. Ma, Y. Duan, A. Rull, M. Kõlvart, K. Taveter	JISA 6(8):1-23, 2015
S03	[S3]	Towards a shared ledger business collaboration language based on data-aware processes	R. Hull, V. S. Batra, Y.-M. Chen, A. Deutsch, F. F. T. Heath III, V. Vianu	ICSOC'16:18-36, 2016
S04	[S4]	Safer smart contracts through type-driven development. Using dependent and polymorphic types for safer development of smart contracts	J. Pettersson, R. Edström	MsThesis'16, 2016
S05	[S5]	From institutions to code: Towards automated generation of smart contracts	C. K. Frantz, M. Nowostawski	FAS*W'16:210-215, 2016
S06	[S6]	Hawk: The Blockchain Model of Cryptography and Privacy-Preserving Smart Contracts	A. E. Kosba, A. Miller, E. Shi, Z. Wen, C. Papamanthou	SP'16:839-858, 2016
S07	[S7]	Obsidian: A Safer Blockchain Programming Language	M. Coblenz	ICSE-C'17: 97-99, 2017
S08	[S8]	Designing secure Ethereum smart contracts: A finite state machine based approach	A. Mavridou, A. Laszka	CoRR'17:1708.03778, 2017
S09	[S9]	TRiC: Terms, RIghts and Conditions Semantic Descriptors for Smart Contracts	L. D. Ibáñez and E. Simperl	ESWC'17:317-326, 2017
S10	[S10]	Simplicity: A new language for blockchains	R. O'Connor	PLAS@CSS'17:107-120, 2017
S11	[S11]	Automated Execution of Financial Contracts on Blockchains	B. Egelund-Müller, M. Elsman, F. Henglein, O. Ross	BISE 59(6): 457-467, 2017
S12	[S12]	Findel: Secure derivative contracts for ethereum	A. Biryukov, D. Khovratovich, S. Tikhomirov	FC'17: 453-467, 2017
S13	[S13]	Recent Developments in Blockchain	V. Dhillon, D. Metcalf, M. Hooper	Chapter:151-181, 2017
S14	[S14]	Smart Contract Negotiation in Cloud Computing	V. Scoca, R. B. Uriarte, R. D. Nicola	CLOUD'17:592-599, 2017
S15	[S15]	ShadowEth: Private Smart Contract on Public Blockchain	R. Yuan, Y-B. Xia, H-B. Chen, B-Y. Zang, J. Xie	JCST 33(3):542-556, 2018
S16	[S16]	Formal Modeling and Verification of Smart Contracts	X. Bai, Z. Cheng, Z. Duan, K. Hu	ICSCA'18:322-326, 2018
S17	[S17]	Fun with Bitcoin smart contracts	M. Bartoletti, T. Cimoli, R. Zunino	ISoLA'18:432-449, 2018
S18	[S18]	Scilla: a smart contract intermediate-level language	I. Sergey, A. Kumar, A. Hobor	CoRR'18:1801.00687, 2018
S19	[S19]	Ekiden: A Platform for Confidentiality-Preserving, Trustworthy, and Performant Smart Contract Execution	R. Cheng, F. Zhang, J. Kos, W. He, N. Hynes, N. M. Johnson, A. Juels, A. Miller, D. Song	CoRR'18:1804.05141, 2018
S20	[S20]	Formal Verification of Smart Contracts Based on Users and Blockchain Behaviors Models	T. Abdellatif , K. Brousmiche	NTMS'18: 1-5, 2018
S21	[S21]	BitML: a calculus for Bitcoin smart contracts	M. Bartoletti, R. Zunino	CCS'18:83-100, 2018
S22	[S22]	Quantitative analysis of smart contracts	K. Chatterjee, A. K. Goharshady, Y. Velner	ESOP'18:739-767, 2018
S23	[S23]	Tool Demonstration: FSolidM for Designing Secure Ethereum Smart Contracts	A. Mavridou, A. Laszka	POST'18:270-277, 2018
S24	[S24]	SPESC: A Specification Language for Smart Contracts	X. He, B. Qin, Y. Zhu, X. Chen, Y. Liu	COMPSAC'18:132-137, 2018
S25	[S25]	Writing Safe Smart Contracts in Flint	F. Schrans, S. Eisenbach, S. Drossopoulou	ASCP'17: 218-219, 2017
S26	[S26]	An introduction to Commitment Based Smart Contracts using ReactionRuleML	J. de Kruijff, H. Weigand	VMBO'18: 149-157, 2018
S27	[S27]	A Method of Logic-Based Smart Contracts for Blockchain System	J. Hu, Y. Zhong	ICDPA'18:58-61, 2018
S28	[S28]	Marlowe: Financial Contracts on Blockchain	P. Lamela Seijas, S. J. Thompson	ISoLA'18:356-375, 2018

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Table 1. Selected primary studies

ID	Ref	Title	Author(s)	Venue
S29	[S29]	Empowering Business-Level Blockchain Users with a Rules Framework for Smart Contracts	T. Astigarraga, X. Chen, Y. Chen, J. Gu, R. Hull, L. Jiao, Y. Li, P. Novotný	ICSOC'18:111-128, 2018
S30	[S30]	SmaCoNat: Smart Contracts in Natural Language	E. Regnath, S. Steinhorst	FDL'18:5-16, 2018
S31	[S31]	Smart Contracts Using Blockly: Representing a Purchase Agreement Using a Graphical Programming Language	T. Weingärtner, R. Rao, J. Ettlin, P. Suter, P. Dublanc	CVCBT'18:55-64, 2018
S32	[S33]	Secure Smart Contract System Built on SMPC Over Blockchain	Y. Zhu, X. Song, S. Yang, Y. Qin, Q. Zhou	iThings'18:1539-1544, 2018
S33	[S34]	Formal Requirement Enforcement on Smart Contracts Based on Linear Dynamic Logic	N. Sato, T. Tateishi, S. Amano	iThings'18:945-954, 2018
S34	[S35]	ZoKrates - Scalable Privacy-Preserving Off-Chain Computations	J. Eberhardt, S. Tai	iThings'18:1084-1091, 2018
S35	[S36]	Mandala: A Smart Contract Programming Language	M. Knecht	CoRR'19:1911.11376, 2019
S36	[S37]	Conditional Formalization of Smart Contract Using Semantic Web Rule Language	S. H. Na, J. H. An, J. S. Yang, Y. B. Park	JEASCI 13(11):8716-8721, 2018
S37	[S38]	Towards Adding Variety to Simplicity	N. Valliappan, S. Mirliaz, E. Lobo Vesga, A. Russo	ISoLA'18:414-431, 2018
S38	[S39]	Pluralize: a Trustworthy Framework for High-Level Smart Contract-Draft	Z. Dargaye, A. Del Pozzo, S. Tucci Piergiovanni	CoRR'18:1812.05444, 2018
S39	[S40]	Light-Weight Programming Language for Blockchain	J. Song, M. Kim, N. D. Lane, R. K. Balan, F. Kawsar, Y. Liu	MobiSys'19:653-654, 2019
S40	[S41]	Towards Agent-Oriented Blockchains: Autonomous Smart Contracts	G. Ciatto, A. Maffi, S. Mariani, A. Omicini	PAAMS'19:29-41, 2019
S41	[S42]	Proof-Carrying Smart Contracts	T. D. Dickerson, P. Gazzillo, M. Herlihy, V. Saraph, E. Koskinen	FCWS'18:325-338, 2018
S42	[S43]	Enriching Smart Contracts with Temporal Aspects	F. Fournier, I. Skarbovsky	ICBC'19:126-141, 2019
S43	[?]	Automatic smart contract generation using controlled natural language and template	T. Tateishi, S. Yoshihama, N. Sato, S. Saito	JRD'19 63(6):1-12, 2019
S44	[S45]	Beagle: A New Framework for Smart Contracts Taking Account of Law	W-T Tsai, N. Ge, J. Jiang, K. Feng, J. He	SOSE'19, 2019
S45	[S46]	Introducing CommitRuleML for Smart Contracts	J. de Kruijff, H. Weigand	VMBO'19, 2019
S46	[S47]	Katallassos: A standard framework for finance	B. França, S. Radermacher, R. Trinkler	CoRR'19:1903.01600, 2019
S47	[S48]	A Model-Driven Approach to Smart Contract Development	K. Boogaard	MsThesis'19, 2019
S48	[S49]	EthIR: A framework for high-level analysis of Ethereum bytecode	E. Albert, P. Gordillo, B. Livshits, A. Rubio, I. Sergey	ATVA'18:513-520, 2018
S49	[S49]	Peer-to-peer Affine Commitment Using Bitcoin	K. Crary, M. J. Sullivan	PLDI'15:479-488, 2015
S50	[S51]	IELE: A Rigorously Designed Language and Tool Ecosystem for the Blockchain	T. Kasampalis, D.Guth, B.M. Moore, T.-F. Serbanuta, Y. Zhang, D. Filaretti, V. N. Serbanuta, R. Johnson, G. Rosu	FM'19:593-610, 2019
S52	[S52]	A Minimal Core Calculus for Solidity Contracts	M. Bartoletti, L. Galletta, M. Murgia	DPMandCBT@ESORICS'19:233-243, 2019
S52	[S53]	A Three-Layered Approach for Designing Smart Contracts in Collaborative Processes	A. Bagozi, D. Bianchini, V. De Antonellis, M. Garda, M. Melchiori	OTM'19:440-457, 2019
S53	[S54]	Towards Self-automatable and Unambiguous Smart Contracts: Machine Natural Language	P. Qin, J. Guo, B. Shen, Q. Hu	ICEBE'19:479-491, 2019
S54	[S55]	Das Contract - A Visual Domain Specific Language for Modeling Blockchain Smart Contracts	M. Skotnica, R. Pergl	EEWC'19:149-166, 2019
S55	[S56]	A Java Framework for Smart Contracts	F. Spoto	WTSC@FC'19:122-137, 2019

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Table 1. Selected primary studies

ID	Ref	Title	Author(s)	Venue
S56	[S57]	Modeling of Smart Contracts in Blockchain Solution for Renewable Energy Grid	T. Górski, J. Bednarski	EUROCAST'19:507-514, 2019
S57	[S58]	Smart Contract Locator (SCL) and Smart Contract Description Language (SCDL)	A. Lamparelli, G. Falazi, U. Breitenbücher, F. Daniel, F. Leymann	ICSOC@TBCE'19:195-210, 2019
S58	[S59]	Aplos: Smart Contracts Made Smart	E. Bandara, W.K. Ng, N. Ranasinghe, K. De Zoysa	BlockSys'19:431-445, 2019
S59	[S60]	On the Prediction of Smart Contracts' Behaviours	C. Laneve, C. Sacerdoti Coen, A. Veschetti	Chapter'19:397-415,2019
S60	[S61]	Secure Smart Contract Generation Based on Petri Nets	N. Zupan, P. Kasinathan, J. Cuellar, M. Sauer	Chapter'20:73-98,2020
S61	[S62]	ConCert: A Smart Contract Certification Framework in Coq	D. Annenkov, J. Botsch Nielsen, B. Spitters	CPP'20:215-228,2020
S62	[S63]	Smart Contracts as Authorized Production Rules	B. Lippmeier, A. Robinson, A. Muys	PPDP'19:1-14,2019
S63	[S64]	Porthos: Macroprogramming Blockchain Systems	A. Mizzi, J. Ellul, G. J. Pace	NTMS'19:1-5, 2019
S64	[S65]	Semantic Smart Contracts for Blockchain-based Services in the Internet of Things	H. Baqa, N.B. Truong, N. Crespi, and G.M. Lee and F. le Gall	NCA'19:1-5,2019
S65	[S66]	Supporting reuse of smart contracts through service orientation and assisted development	L. Guida, F. Daniel, A. Kupper, J. Xu, Y. Park, P. Ruppel, S. Schulte	DAPPCON'19: 59-68, 2019
S66	[S67]	Modularizing cross-cutting concerns with aspect-oriented extensions for solidity	C.-C. Hung, K. Chen, C.-F.Liao, A. Kupper, J. Xu, Y. Park, P. Ruppel, S. Schulte	DAPPCON'19:176-181 ,2019
S67	[S68]	Zkay: Specifying and enforcing data privacy in smart contracts	S. Steffen, N. Melchior, B. Bichsel, P. Tsankov, M. Gersbach, M. Vechev	CSS'19:1759–1776, 2019
S68	[S69]	Resource-Aware Session Types for Digital Contracts	A. Das, S. Balzer, J. Hoffmann, F. Pfenning	CoRR'19:1902.06056
S69	[S70]	Domain Specific Language for Smart Contract Development	M. Wöhrer, U. Zdun	ICBC'20, 2020
S70	[S71]	Safer Smart Contract Programming with Scilla	I. Sergey, V. Nagaraj, J. Johannsen, A. Kumar, Amrit, A. Trunov, K.C.G. Hao	OOSPLA'19:1-30,2019

A.2 Selected papers of grey literature

Table 2. Selected grey literature

ID	Ref	Title	Author(s)	Contribution Type	Year
G01	[G1]	Smart-contract value-transfer protocols on a distributed mobile application platform	P. Dai, N. Mahi, J. Earls, A. Norta	Whitepaper	2017
G02	[G2]	The Pact smart contract language	S. Popejoy	Whitepaper	2017
G03	[G2]	A modern programming language for smart contracts	N. Roberts	Tech-Report	2018
G04	[G4]	A Formal Language for Analyzing Contracts	N. Szabo	Website	2002
G05	[G5]	Script	Roconnor	Wikipage	2016
G06	[G6]	BALZaC. Bitcoin Abstract Language, analyZer and Compiler	M. Hearn	Website	2018
G07	[G7]	DAML SDK Documentation	Digital Asset	Website	2017
G08	[G8]	Ivy for Bitcoin: a smart contract language that compiles to Bitcoin Script	Chain	Blog page	2017
G09	[G9]	Bamboo: a language for morphing smart contracts	Cornell Blockchain	GitHub page	2017
G10	[G10]	Babbage - a mechanical smart contract language	Christian	Blog page	2017
G11	[G11]	Zen Protocol's Smart Contract Paradigm - Zen Protocol	A. Manning	Blog page	2017
G12	[G12]	fi - smart coding for smart contracts	Stephen Andrews	website	2018
G13	[G13]	Codius - White paper	E. Schwartz,S. Thomas	Whitepaper	2018
G14	[G14]	The Liquidity Language for smart contracts	F. Le Fessant, A. Mebsout, D. Declerk, A. Champion	Website	2018
G15	[G15]	Michelson: the language of Smart Contracts in Tezos	Nomadic Labs	Website	2018
G16	[G16]	Formal Specification of the Plutus Core Language (rev. 10)	M. P. Jones	GitHub page	2018
G17	[G17]	Contracts, Composition, and Scaling. The Rholang specification	L. G. Meredith, J. Pettersson, G. Stephenson, M. Stay, K. Shikama, J. Denman	Technical Report	2018
G18	[G18]	Vyper - Vyper documentation	V. Buterin	Website	2018
G19	[G19]	Unibright-the unified framework for blockchain based business integration	S. Schmidt, M. Jung, T. Schmidt, I. Sterzinger, G. Schmidt, M. Gomm, K. Tschirschke, T. Reisinger, F. Schlarb, D. Benkenstein, B. Emig	Whitepaper	2018
G20	[G20]	Solidity Documentation	Ethereum	Website	2019
G21	[G21]	Tezos, a self-amending crypto-ledger. White paper	G. Alfour	Blog page	2019
G22	[G22]	ZF*	A.L. Manning	Website	2017
G23	[G23]	Aeternity documentation	aethernity workgroup	Website	2018
G24	[G24]	IELE Semantics	Everett Hildenbrandt and Dwight Guth	GitHub page	2018
G25	[G25]	NEO White paper	NEO Team	White paper	2018
G26	[G26]	cicero	Accord Project Technology Working Group	GitHub page	2018
G27	[G27]	ACTUS: The algorithmic representation of financial contracts	N. Bundi	Whitepaper	2018
G28	[G28]	OpenLaw Documentation	A. Wright, D. Roon, ConsenSys AG	Website	2019
G29	[G29]	Zether: Towards Privacy in a Smart Contract World	B. Bünz, S. Agrawal, M. Zamani, D. Boneh	Whitepaper	2019
G30	[G30]	Ergo Language Guide	Accord Project	Website	2019
G31	[G31]	Smart contracts and trust contracts: part 3	BOScoin	Blog	2017
G32	[G32]	Write your next Ethereum Contract in Pyramid Scheme	M. Burge	Blog	2017
G33	[G33]	IELE: An intermediate level Blockchain language designed and implemented using formal semantics Model-Driven Approach to Smart Contract Development	T. Kasampalis, D. Guth, B. Moore, T. Serbanuta, V. Serbanuta, D. Filaretti, G. Rosu, R. Johnson	Whitepaper	2018
G34	[G34]	Deon Digital CSL Language Guide Documentation	Deon Digital	Website	2019
G35	[G35]	What is Archetype	B. Rognier	Website	2019
G36	[G36]	RIDE: a Smart Contract Language for Waves	A. Begicheva,I. Smagin	White paper	2018

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Table 2. Selected grey literature

ID	Ref	Title	Author(s)	Contribution Type	Year
G37	[G37]	Writing safe smart contracts in Flint	Franklin Schrans	Report	2018
G38	[G38]	Move: A Language With Programmable Resources	S. Blackshear, E. Cheng, D. L. Dill, V. Gao, B. Maurer, T. Nowacki, A. Pott, S. Qadeer, Rain, D. Russi, S. Sezer, T. Zakian, R. Zhou	Whitepaper	2020
G39	[G39]	Yul	Ethereum Foundation	Website	2020

B APPENDIX. OTHER DETAILED TABLES

B.1 Citations per study

Table 3. Papers ordered by the citations in white literature.

Rank	ID	Title	Google Scholar	Scopus	Web of Science	Altimetrics
1	S06	Hawk: The Blockchain Model of Cryptography and Privacy-Preserving Smart Contracts	1250	601	314	3311
2	S19	Ekiden: A Platform for Confidentiality-Preserving, Trustworthy, and Performant Smart Contract Execution	111	-	-	-
3	S05	From institutions to code: Towards automated generation of smart contracts	94	50	23	601
4	S18	Scilla: a smart contract intermediate-level language	80	-	-	-
5	S03	Towards a shared ledger business collaboration language based on data-aware processes	73	31	13	357
6	S08	Designing secure Ethereum smart contracts: A finite state machine based approach	73	4	0	-
7	S11	Automated Execution of Financial Contracts on Blockchains	58	28	20	321
8	S10	Simplicity: A new language for blockchains	58	19	-	192
9	S02	eContractual choreography-language properties towards cross-organizational business collaboration	42	36	23	131
10	S07	Obsidian: A Safer Blockchain Programming Language	40	17	11	255
11	S20	Formal Verification of Smart Contracts Based on Users and Blockchain Behaviors Models	34	20	2	162
12	S48	EthIR: A Framework for High-Level Analysis of Ethereum Bytecode	34	7	-	79
13	S23	FSolidM for Designing Secure Ethereum Smart Contracts	33	13	5	102
14	S34	ZoKrates-Scalable Privacy-Preserving Off-Chain Computations	33	13	3	58
15	S12	Findel: Secure derivative contracts for ethereum	30	17	-	87
16	S15	ShadowEth: Private Smart Contract on Public Blockchain	29	14	6	247
17	S21	BitML: a calculus for Bitcoin smart contracts	27	9	4	149
18	S01	Distributed Electronic Rights in JavaScript	26	6	4	72
19	S22	Quantitative analysis of smart contracts	24	10	-	106
20	S49	Peer-to-peer Affine Commitment Using Bitcoin	22	10	5	79
21	S14	Smart Contract Negotiation in Cloud Computing	20	14	13	68
22	S28	Marlowe: Financial Contracts on Blockchain	19	6	-	32
23	S16	Formal Modeling and Verification of Smart Contracts	18	10	6	86
24	S25	Writing Safe Smart Contracts in Flint	17	7	-	74
25	S70	Safer Smart Contract Programming with Scilla	14	-	-	7
26	S29	Empowering Business-Level Blockchain Users with a Rules Framework for Smart Contracts	9	5	-	20
27	S17	Fun with Bitcoin smart contracts	8	4	-	14
28	S24	SPESC: A Specification Language for Smart Contracts	7	6	-	57
29	S04	Safer smart contracts through type-driven development. Using dependent and polymorphic types for safer development of smart contracts	6	-	-	-
30	S50	IELE: A Rigorously Designed Language and Tool Ecosystem for the Blockchain	5	1	-	4
31	S51	A Minimal Core Calculus for Solidity Contracts	5	1	-	4

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Table 3. Papers ordered by the citations in white literature.

Rank	ID	Title	Google Scholar	Scopus	Web of Science	Altimetrics
32	S67	Zkay: Specifying and enforcing data privacy in smart contracts	5	1	0	67
33	S30	SmaCoNat: Smart Contracts in Natural Language	4	2	0	47
34	S57	Smart Contract Locator (SCL) and Smart Contract Description Language (SCDL)	4	1	-	-
35	S65	Supporting reuse of smart contracts through service orientation and assisted development	4	2	1	22
36	S68	Resource-Aware Session Types for Digital Contracts	4	-	-	-
37	S40	Towards Agent-Oriented Blockchains: Autonomous Smart Contracts	3	1	-	13
38	S38	Pluralize: a Trustworthy Framework for High-Level Smart Contract-Draft	3	-	-	-
39	S13	Recent Developments in Blockchain	2	-	-	168
40	S31	Smart contracts using blockly: Representing a purchase agreement using a graphical programming language	2	2	1	38
41	S33	Formal requirement enforcement on smart contracts based on linear dynamic logic	2	2	2	26
42	S37	Towards adding variety to simplicity	2	1	-	15
43	S55	A Java Framework for Smart Contracts	2	0	-	1
44	S59	On the Prediction of Smart Contracts' Behaviours	2	0	-	5
45	S43	Automatic smart contract generation using controlled natural language and template	2	0	0	25
46	S26	An introduction to Commitment Based Smart Contracts using ReactionRuleML	1	0	-	-
47	S27	A Method of Logic-Based Smart Contracts for Blockchain System	1	1	-	34
48	S41	Proof-Carrying Smart Contracts	1	1	-	24
49	S44	Beagle: A new framework for smart contracts taking account of law	1	1	0	15
50	S47	A Model-Driven Approach to Smart Contract Development	1	-	-	-
51	S52	A Three-Layered Approach for Designing Smart Contracts in Collaborative Processes	1	0	-	5
52	S56	Modeling of Smart Contracts in Blockchain Solution for Renewable Energy Grid	1	0	-	-
53	S61	ConCert: A Smart Contract Certification Framework in Coq	1	0	-	15
54	S64	Semantic Smart Contracts for Blockchain-based Services in the Internet of Things	1	0	-	10
55	S69	Domain Specific Language for Smart Contract Development	1	-	-	-
56	S35	Mandala: A Smart Contract Programming Language	1	-	-	-
57	S09	TRiC: Terms, RIghts and Conditions Semantic Descriptors for Smart Contracts	0	0	-	27
58	S39	Light-Weight Programming Language for Blockchain	0	-	-	8
59	S42	Enriching Smart Contracts with Temporal Aspects	0	0	0	18
60	S45	Introducing commitRuleML for smart contracts	0	0	-	-
61	S32	Secure Smart Contract System Built on SMPC over Blockchain	0	0	0	26
62	S46	Katal: A standard framework for finance	0	-	-	-
63	S53	Towards Self-automatable and Unambiguous Smart Contracts: Machine Natural Language	0	0	-	-
64	S54	Das Contract - A Visual Domain Specific Language for Modeling Blockchain Smart Contracts	0	0	-	6
65	S58	Aplos: Smart Contracts Made Smart	0	0	-	4
66	S60	Secure Smart Contract Generation Based on Petri Nets	0	-	-	6
67	S62	Smart Contracts as Authorized Production Rules	0	0	0	10
68	S63	Porthos: Macroprogramming Blockchain Systems	0	0	0	10
69	S66	Modularizing cross-cutting concerns with aspect-oriented extensions for solidity	0	0	0	14
70	S36	Conditional formalization of smart contract using semantic web rule language	-	0	-	18 18

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Table 3. Papers ordered by the citations in white literature.

Rank	ID	Title	Google Scholar	Scopus	Web of Science	Altimetrics

B.2 Number of papers by venue

Table 4. Venues ordered by number of studies published

Rank	Venue	Type	No. of papers
1	CoRR	arxiv	6
2	International Symposium on Leveraging Applications of Formal Methods (ISoLA)	conference	3
3	International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData)	conference	3
4	International Conference on Financial Cryptography and Data Security (FC)	conference	3
5	International Workshop on Value Modeling and Business Ontologies (VMBO)	workshop	2
6	International Conference on Service-Oriented Computing (ICSOC)	conference	2
7	International Conference on New Technologies, Mobility and Security (NTMS)	conference	2
8	International Conference on Decentralized Applications and Infrastructures (DAPPCON)	conference	2
9	International Conference on Blockchain and Cryptocurrency (ICBC)	conference	2
10	European Symposium on Programming (ESOP)	conference	2
11	Conference on Computer and Communications Security (CCS)	conference	2
12	Workshop on Trusted SmartContracts (WTSC)	workshop	1
13	Workshop on Programming Languages and Analysis for Security (PLAS)	workshop	1
14	Towards Blockchain-Based Collaborative Enterprise Workshop (TBCE)	workshop	1
15	Symposium on Security and Privacy(SP)	conference	1
16	On the Move to Meaningful Internet Systems Conferences (OTM)	conference	1
17	Object-Oriented Programming, Systems, Languages & Applications Conference (OOSPLA)	conference	1
18	Journal of Internet Services and Applications (JISA)	journal	1
19	Journal of Engineering and Applied Sciences (JEAS)	journal	1
20	Journal of Computer Science and Technology (JCST)	journal	1
21	International Workshops on Foundations and Applications of Self-Systems (FAS-W)	workshop	1
22	International Workshop on Linked Data and Distributed Ledgers (LD-DL)	workshop	1
23	International Symposium on Principles and Practice of Programming Languages (PPDP)	conference	1
24	International Symposium on Network Computing and Applications (NCA)	conference	1
25	International Symposium on Formal Methods (FM)	conference	1
26	International Symposium Automated Technology for Verification and Analysis (ATVA)	conference	1
27	International Conference on e-Business Engineering (ICEBE)	conference	1
28	International Conference on Software and Computer Applications (ICSCA)	conference	1
29	International Conference on Software Engineering Companion (ICSE-C)	conference	1
30	International Conference on Service-Oriented System Engineering (SOSE)	conference	1
31	International Conference on Practical Applications of Agents and Multi-Agent Systems (PAAMS)	conference	1
32	International Conference on Data Processing and Applications (ICDPA)	conference	1
33	International Conference on Computer Aided Systems Theory (EUROCAST)	conference	1
34	International Conference on Cloud Computing (CLOUD)	conference	1
35	International Conference on Blockchain and Trustworthy Systems (BlockSys)	conference	1
36	International Conference on Art, Science, and Engineering of Programming (ASCP)	conference	1
37	IBM Journal of Research and Development (JRD)	journal	1
38	Forum on Specification & Design Languages (FDL)	conference	1
39	Enterprise Engineering Working Conference (EEWC)	conference	1
40	Data Privacy Management, Cryptocurrencies and Blockchain Technology (DPM and CBT)	workshop	1
41	Crypto Valley Conference on Blockchain Technology (CVCBT)	conference	1
42	Conference on Programming Language Design and Implementation (PLDI)	conference	1
43	Business & Information Systems Engineering (BISE)	journal	1
44	Annual Computer Software and Applications Conference (COMPSAC)	conference	1
45	ACM SIGPLAN International Conference on Certified Programs and Proofs (CPP)	conference	1

B.3 Implementation languages

Table 5. Implementation languages.

Language	Id Studies	Level	Paradigm
Babbage	G10	Conceptual-level	Symbolic
Bamboo	G09	High-level	Declarative
Plurality	S38	High-level	Declarative
Porthos	S63	High-level	Declarative
Qtum Smart-Contract Language (QSCL)	G01	High-level	Declarative
Rholang	G17	High-level	Declarative
Tenderfone	S40	High-level	Declarative
Vyper	G18	High-level	Declarative
Balzac	G06	High-level	Imperative
fi	G12	High-level	Imperative
Ivy	G08	High-level	Imperative
Liquidity	G14	High-level	Imperative
Obsidian	S07	High-level	Imperative
Solidity	G20	High-level	Imperative
Takamaka	S55	High-level	Imperative
Contract Modeling Language (CML)	S69	High-level	Imperative,Declarative
Pyramid Scheme	G32	High-level	Imperative,Declarative
Pact	G02	Intermediate-level	Declarative
Smart contract intermediate-level language (Scilla)	S18,S70	Intermediate-level	Declarative
Move	G38	Intermediate-level	Imperative
Yul	G39	Intermediate-level	Imperative
Michelson	G15	Intermediate-level/Low-level?	Declarative
Plutus Core	G16	Low-level languages for UTXO scripting	Declarative
Simplicity	S10	Low-level languages for UTXO scripting	Declarative
Script	G05	Low-level languages for UTXO scripting	Imperative
Aplos	S58	-	Declarative
DAML	G07	-	Declarative
Ekiden	S19	-	Declarative
Idris	S04	-	Declarative
lambda-smart	S61	-	Declarative
LIGO	G21	-	Declarative
Logic-SC	S27	-	Declarative
Mandala	S35	-	Declarative
Marlowe	S28	-	Declarative
Nomos	S68	-	Declarative
S36	S36	-	Declarative
S60	S60	-	Declarative
Zether smart contract (ZSC)	G29	-	Declarative
Bounty Contract	S15	-	Imperative
Chain Core	S13	-	Imperative
Codius	G13	-	Imperative
Contract Specification Language (CSL)	G34	-	Imperative
Ergo	G30	-	Imperative
Hawk	S06	-	Imperative
koa	S39	-	Imperative
NEO smart contracts	G25	-	Imperative
RIDE	G36	-	Imperative
S22	S22	-	Imperative
S32	S32	-	Imperative
S42	S42	-	Imperative
S66	S66	-	Imperative
Trust Contract	G31	-	Imperative
Typecoin	S49	-	Imperative

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Table 5. Implementation languages.

Language	Id Studies	Level	Paradigm
ZoKrates	S34	-	Imperative
G03	G03	-	Imperative, Declarative
Sophia	G23	-	Imperative, Declarative
Archetype	G35	-	Imperative,Declarative
Dr. SES	S01	-	Imperative,Declarative
DSL	S33	-	Imperative,Declarative
scl	S59	-	Symbolic

B.4 Specification languages

Table 6. Specification languages.

Language	Id Studies	Paradigm
BIP Framework	S20	Declarative
Das Contract	S54	Declarative
UML Profile for Smart Contracts	S56	Declarative
Blockly	S31	Symbolic
Business Collaboration Rules Language (BCRL)	S29	Declarative
Cicero	G26	Declarative
Findel	S12	Declarative
OpenLaw	G28	Declarative
Proof-Carrying Smart Contracts (PCSC)	S41	Declarative
Rainfall	S62	Declarative
Reaction RuleML	S26	Declarative
Unibright Contract Interface	G19	Declarative
eSourcing Markup Language (eSML)	S02	Imperative
Rule Based Representation (RBR)	S48	Symbolic
zkay	S67	Symbolic
Abstract Smart Contracts (ASC)	S52	Declarative
ADICO-Solidity	S05	Declarative
Beagle	S44	Declarative
Business Collaboration Language (BCL)	S03	Declarative
CommitRuleML	S45	Declarative
DSL4SC	S43	Declarative
dSLAC	S14	Declarative
eDSL	S37	Declarative
G04	G04	Declarative
S11	S11	Declarative
S16	S16	Declarative
S47	S47	Declarative
S53	S53	Declarative
S64	S64	Declarative
S65	S65	Declarative
SmaCoNat	S30	Declarative
Smart Contract Description Language (SCDL)	S57	Declarative
SPECS	S24	Declarative
TinySol	S51	Declarative
TRiC	S09	Declarative

B.5 Languages by focus

Table 7. Languages per focus

Focus	Languages
Business Process	Business Collaboration Language (BCL), Business Collaboration Rules Language (BCRL), Unibright Contract Interface, eSourcing Markup Language (eSML)

Continues on the next page...

Table 7. Languages per focus

Focus	Languages
Contract Composition	Contract Specification Language (CSL)
Financial	ACTUS, DAML, Findel, G04, Marlowe, Move, NEO smart contracts, Plutus, Porthos, Proof-Carrying Smart Contracts (PCSC), S11, Trust Contract, ZF*
Formalisation	DSL, TinySol, Typecoin, eDSL
General Purpose	Ivy, Rholang, Script, Solidity
Improve Development	fi
Increase Level of Abstraction	Liquidity
Interactions	Porthos, Qtum Smart-Contract Language (QSCL), Rholang, S22, SPECS, dSLAC, scl
Legal	ADICO-Solidity, Babbage, Beagle, Blockly, CommitRuleML, Ergo, NEO smart contracts, Nomos, OpenLaw, Reaction RuleML
Model-driven	Contract Modeling Language (CML), S47, UML Profile for Smart Contracts
Natural Language	Cicero, DSL4SC, S53,SmaCoNat
Ontology	S36, TRiC
Optimization	Sophia, Yul
Oracles	Codius, Plurality
Other	Aplos, G03, Logic-SC, S42, Takamaka, Tenderfone
Privacy	Bounty Contract, Chain Core, Ekiden, Hawk, Pact, Rainfall, Zether smart contract (ZSC), ZoKrates, zkay
Safety	BitML, Ergo, Idris, Mandala, Move, Simplicity, Smart contract intermediate-level language (Scilla)
Security	Archetype, Bamboo, Dr. SES, Ekiden, FSolidM, Flint, Obsidian, RIDE, S32, S60, Vyper, Zether smart contract (ZSC), koa
Separation of Concerns	Pyramid Scheme, S66
Service-oriented	S64, S65, Smart Contract Description Language (SCDL)
Trust	Abstract Smart Contracts (ASC), Plurality
Verification	BIP Framework, Balzac, FSolid , Findel, G04, IELE, Idris, LIGO, Liquidity, Obsidian, Proof-Carrying Smart Contracts (PCSC), Rule Based Representation (RBR), S16, S22, Simplicity, Smart contract intermediate-level language (Scilla), ZF*, ZoKrates, dSLAC, lambda-smart, scl
Virtual Machine	IELE, Michelson
Visual Specification	Babbage, Blockly, Das Contract

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