的充分性.程序的变异过程可以通过变异算子来实现,每个变异算子对应一种错误类型.越高质量的突变,越能暴露测试套件的缺陷.

Ni 等人[17]在实验部分利用突变测试技术进行错误植入,他们在实验部分选择 6 种突变产生器:ERR,AIE,ACI,ASI,ASF 和 ER,用 A~F 表示.利用这些产生器为 WS-BPEL 源程序产生 34 种错误种子,将这些错误种子植入到源程序中,得到可以进行测试的变异程序.错误种子在 WS-BPEL,WSDL 和 XPath 文档中的分布见表 6.

Table 6 An instance from Ref.[17]

表 6 来自文献[17]中的一个实例

Ref	A	B	C	D	E	F	SUM
WS-BPEL	1	3	2	4	3	0	13
WSDL	0	1	1	1	6	2	11
XPath	3	0	1	2	1	3	10
Total	4	4	4	7	10	5	34

6.3 评测指标

Web 服务组合测试领域所用到的评测指标可以分为两类:一类是测试用例生成技术的评测指标,另一类回归测试的评测指标.经过调查总结,现有研究通常选择测试用例生成数量、约束条件数量、测试用例的覆盖率、测试用例生成时间以及测试用例的检错率 *FAIL* 这些条件中的 1 个或几个作为测试用例生成技术的评测指标.

错误检错率 *FAIL* 定义为能够暴露错误的测试套件占总测试条件数量的比例,计算公式为

$$FAIL=\frac{Number\ of\ FAIL\ verdicts}{Number\ of\ total\ instances}\times 100\% \tag{1}$$

Zhou 等人[35]使用生成的测试用例数量、约束条件数量以及约束文档求解时间来对提出的测试用例生成方法进行评价,从而说明测试用例的充分性以及开发工具的实用性.他们选择 6 个程序进行评测,评测结果见表 7.在表 7 中,Solving time 表示测试用例生成时间,在文献[35]中即为约束文档求解时间;*TC Num* 表示覆盖率达到最大值时已生成测试用例的数量;*CNN*,*CEN* 分别表示覆盖的节点数量和覆盖的路径的数量;*MC\DC Num* 表示覆盖的独立条件\判断语句的数量.*TC Num*,*CNN* 和 *CEN* 的值越大,说明当前执行测试的测试用例程序体覆盖率越大,测试用例的充分性也越高;Solving time 越小,则说明开发工具的实用性越高.

Table 7 An instance from Ref.[35]

表 7 来自文献[35]中的一个实例

Composite Web service	BPEL LOC	Node coverage criterion			Edge coverage criterion			MC/DC coverage criterion		
		TC Num	*CNN*	Solving time	*TC Num*	*CNN*	Solving time	*TC Num*	*CNN*	Solving time
SquaresSum	69	1	4	131	1	7	13	2	2	262
SquaresSum (in 4 loops)	69	1	4	127	1	7	1 127	–	–	–
SquaresSum_1	117	1	7	123	1	11	123	2	2	245
TacService	57	1	4	107	1	5	107	2	2	207
Loan approval service	117	3	6	369	3	15	369	3	3	369
CaculatorProj	190	3	5	393	3	12	393	3	3	393
LargeProcess	129	1	10	168	1	15	168	4	4	636

不同的是,在回归测试研究领域,研究者选择错误检测平均累计比例 APFD、平均相对位置 RP 和故障检测的调和平均数 HMFD 这些指标中的 1 个或几个作为 TCP 的评测指标;一般从两个方面来评价测试套件约简技术(TSM)的效率——测试套件规模减小的百分比和错误发现减少的百分比,如文献[65];将最终选择出的测试子集的规模大小和错误暴露比例作为 TCS 的评测指标,如文献[69,70].

文献[50,51]同时将 APFD,RP 和 HMFD 作为 TCP 技术有效性的评测指标.评测指标 APFD,RP 和 HMFD 的取值均在 0~1 之间.APFD 取值越高,则缺陷检测速度越快;RP 和 HMFD 的取值越低,则意味着缺陷检测速度越快.假设有测试用例集 T,其中包含 n 个测试用例,m 个缺陷,F 为 T 检测到的缺陷集合,给定一个测试用例执行次序,其中,TF_i 表示首个可检测到第 i 个缺陷的测试用例在该执行次序中所处次序,则 APFD 的计算公式为

$$APFD = 1 - \frac{TF_1 + TF_2 + ... + TF_m}{nm} + \frac{1}{2n} \tag{2}$$

HMFD 的计算公式为

$$HMFD = \frac{m}{\frac{1}{TF_1} + \frac{1}{TF_2} + ... + \frac{1}{TF_m}} \tag{3}$$

$P(TF_i,i)$为缺陷 i 导致的第 1 个测试失败的测试用例所在位置为 TF_i 的可能性,缺陷 i 的值可计算为 $RP(i)$:

$$RP(i) = \frac{\sum_{TF_i=1}^{n} TF_i \cdot P(TF_i,i)}{n} \tag{4}$$

7 总结与展望

根据上述分析可以看出,Web 服务组合测试问题已经得到学术界和工业界的广泛关注,并获得了阶段性的成果.本文从 Web 服务组合的特性出发,提出 Web 服务组合测试存在的挑战和 Web 服务组合测试与传统测试的区别,并对 Web 服务组合测试的已有研究成果、评测程序和评测指标进行了系统的总结和分析.

从上述内容的介绍中可以看出,测试用例生成、测试结果评估和回归测试问题是 Web 服务组合测试的重要研究问题.虽然已有研究取得了一定的成果,但是在这些领域内还存在一些进一步研究的问题.主要表现在以下几个方面.

(1) 高检错率、高覆盖量、低冗余度的测试用例

测试用例质量是执行有效的 Web 服务组合测试的根本条件,测试用例的高质量表现在高检错率、低冗余和高覆盖.已有研究工作为提高 Web 服务组合测试的高效性提出了许多测试用例生成技术和方法,以获得高质量的测试用例.从研究成果分析,现有技术生成的测试用例质量不断得到提高,但仍有进一步提高的空间.如何获取更多能够丰富测试信息的约束条件来生成测试用例,是当今学术界和工业界仍需进一步解决的问题.

(2) 自动化的测试工具

Sun 等人[21]实现了能够自动化进行 Web 服务组合测试的工具.该工具能够自动化产生测试用例、自动化执行测试,是实现 Web 服务组合测试自动化的领先者.但该工具没有实现测试流程的整体自动化且存在一些性能缺陷,表现为:测试结果验证与评估需人工完成;Sun 等人没有对该工具的执行时间进行评估,因此无法了解该工具的性能和效率;该工具自动化执行测试的评测程序为 BPEL 引擎提供的合成 Web 服务组合,该服务规模较小.因此,该工具是否适用于复杂度更高的系统还有待进一步研究.

(3) 实际应用中的组合服务作为评测程序

目前,已有的 Web 服务组合测试技术一般采用对照实验方式进行有效性评估,从第 5.1 节可以得出结论:已有测试技术采用的评测服务绝大部分为 BPEL 引擎提供的合成组合服务,只有极少部分研究者选择实际应用中的 Web 服务组合作为评测程序,合成组合服务的程序规模较小,选择该组合服务作为评测程序所得的结论不一定适用于来自实际应用中的大型 Web 服务组合.若要将学术界的 Web 服务组合测试技术应用到实际应用中,则需要进一步提高测试工具的自动化程度,并保证工具具有一定的鲁棒性.若对上述问题提出有效的解决方案,则将有效提高研究成果的应用价值,并大幅度提高实际应用的 Web 服务组合测试效率.

(4) 运行时绑定

部分研究者已经关注 Web 服务组合的运行时绑定问题,如 Sun 等人[21]、Ni 等人[17]、和 Wu 等人[18]分别从场景、消息序列和服务内部状态模型化这 3 个方面实现测试用例生成技术.Sun 等人认为,测试用例生成过程的自动化程度是决定运行时绑定问题解决与否的关键,因此他们设计了测试自动化的原型工具,而 Ni 等人和 Wu 等人没有阐述测试技术的自动化程度.但遗憾的是,Sun 等人没有就自动化程度和运行时绑定问题之间的联系进行实验性的验证,因此无法确定他们所提出的技术是否真正能够解决运行时绑定问题.

(5) 回归测试动态演化

解决动态演化问题,是 Web 服务组合回归测试技术的关键所在.已有研究不断对该问题进行深入研究,从开始着眼于解决回归测试之前的动态演化问题,到提出解决回归测试过程中的动态演化问题,已有研究已经取得一定的成果.但这仅限于 Web 服务组合的 TCP 技术研究领域,在测试用例选择、测试用例修复等其他回归测试技术研究领域处于空白期.

(6) 尝试新 TCP 测试方法

在第 6.3 节,我们对 Web 服务组合已有的 TCP 技术进行了系统的总结和分析,可以看到,现有的 TCP 技术都基于贪婪法进行,并取得了一定的研究成果.除了对基于贪婪法的 TCP 技术展开更为深入的研究之外,我们还可以积极寻找可以行之有效的 TCP 技术方法,如传统软件 TCP 研究中的机器学习法和专家融合知识法.

References:

[1] Hong Z, Feng ZY. Collaborative testing of Web services. IEEE Trans. on Service Computing, 2012,5(1):116−130. [doi: 10.1109/TSC.2010.54]

[2] Bozkurt M, Harman M, Hassoun Y. Testing and verification in service-oriented architecture: A survey. Software Testing, Verification and Reliability, 2013,23(4):261−313. [doi: 10.1002/stvr.1470]

[3] Ebrahim SM. A survey of service-oriented architecture systems testing. Int'l Journal of Software Engineering & Applications (IJSEA), 2012,3(6):19−27. [doi: 10.5121/ijsea.2012.3602]

[4] Rusli HM, Puteg M, Ibrahim S, Tabatabaei S. A comparative evaluation of state-of-the-art Web service composition testing approaches. In: Proc. of the 6th Int'l Workshop on Automation of Software Test (AST). 2011. 29−35. [doi: 10.1145/1982595.1982602]

[5] Huang H, Tsai WT, Paul R. Automated model checking and testing for composite Web services. In: Proc. of the IEEE Int'l Symp. on Object-Oriented Real-time Distributed Computing. 2005. 300−307. [doi: 10.1109/ISORC.2005.16]

[6] Garcia-Fanjul J, de la Riva C, Tuya J. Generating test cases specifications for BPEL compositions of Web services using SPIN. In: Proc. of the Int'l Workshop on Web Services—Modeling and Testing. 2006. 83−94.

[7] Garcia-Fanjul J, de La Riva C, Tuya J. Generation of conformance test suites for compositions of Web services using model checking. In: Proc. of the Testing: Academic and Industrial Conf.—Practice and Research Techniques. 2006. 127−130. [doi: 10.1109/TAIC-PART.2006.11]

[8] Zheng YY, Zhou J, Krause P. A model checking based test case generation framework for Web services. In: Proc. of the Int'l Conf. on Information Technology. 2007. 715−722. [doi: 10.1109/ITNG.2007.8]

[9] Li B, Zhang WS, Zhang XG. Describing and verifying Web service using CCS. In: Proc. of the Int'l Conf. on Parallel and Distributed Computing. 2006. 1571−1576. [doi: 10.1109/PDCAT.2006.52]

[10] Long HY, Ma D. Checking compatibility of BPEL4WS based on CCS. In: Proc. of the Int'l Conf. on System Science, Engineering Design and Manufacturing Informatization. 2011. 255−258. [doi: 10.1109/ICSSEM.2011.6081199]

[11] Du YH, Tan W, Zhou MC. Timed compatibility analysis of Web service composition a modular approach based on Petri nets. IEEE Trans. on Automation Science and Engineering, 2014,11(2):594−606. [doi: 10.1109/TASE.2013.2253552]

[12] Yuan Y, Li Z, Sun W. A graph-search based approach to BPEL4WS test generation. In: Proc. of the Int'l Conf. on Software Engineering Advances (ICSEA). 2006. 1−14. [doi: 10.1109/ICSEA.2006.261270]

[13] Yan J, Li Z, Yuan Y, Sun W, Zhang J. BPEL4WS unit testing: Test case generation using a concurrent path analysis approach. In: Proc. of the 17th Int'l Symp. on Software Reliability Engineering (ISSRE). 2006. 75−84. [doi: 10.1109/ISSRE.2006.16]

[14] Mei L, Chan WK, Tse TH. Data flow testing of service choreography. In: Proc. of the 7th Joint Meeting of the European Software Engineering Conf. and the ACM SIGSOFT Int'l Symp. on Foundations of Software Engineering (ESEC). 2009. 151−160. [doi: 10.1145/1595696.1595720]

[15] Mei L, Chan WK, Tse TH. Data flow testing of service oriented workflow applications. In: Proc. of the 30th Int'l Conf. on Software Engineering (ICSE). 2008. 371−380. [doi: 10.1145/1368088.1368139]

[16] Hou SS, Zhang L, Lan Q, Mei HJ, Sun S. Generating effective test sequences for BPEL testing. In: Proc. of the 5th Int'l Conf. on Quality Software. 2009. 331−340. [doi: 10.1109/QSIC.2009.50]

[17] Ni Y, Hou SS, Zhang L, Zhu J, Li ZJ, Lan Q. Effective message-sequence generation or testing BPEL programs. IEEE Trans. on Service Computing, 2013,6(1):7−19. [doi: 10.1109/TSC.2011.22]

[18] Wu CS, Huang CH. The Web services composition testing based on extended finite state machine and UML model. In: Proc. of the IEEE Int'l Conf. on Service Science and Innovation. 2013. 215−222. [doi: 10.1109/ICSSI.2013.46]

[19] Sun CA, Shang Y, Zhao Y, Chen TY. Scenario-Oriented testing for Web service compositions using BPEL. In: Proc. of the 12th Int'l Conf. on Quality Software (QSIC). 2012. 171−174. [doi: 10.1109/QSIC.2012.47]

[20] Zhang PC, Leung H, Li WR, Li XD. Web services property sequence chart monitor: A tool chain for monitoring BPEL-based Web service composition with scenario-based specifications. IET Software, 2013,7(4):222−248. [doi: 10.1049/iet-sen.2012.0047]

[21] Sun C, Zhao Y, Pan L, Liu H, Chen TY. Automated testing of WS-BPEL service compositions: A scenario-oriented approach. IEEE Trans. on Services Computing, 2015. [doi: 10.1109/TSC.2015.2466572]

[22] Zhang G, Rong M, Zhang J. A business process of Web services testing method based on UML 2.0 activity diagram. In: Proc. of the Intelligent Information Technology Application Workshop. 2007. 59−65. [doi: 10.1109/IITA.2007.83]

[23] BellF, Endo AT, Linschulte M, Simao AS. Model-Based testing of Web service compositions. In: Proc. of the 6th IEEE Int'l Symp. on Service-Oriented System Engineering (SOSE). 2011. 181−192. [doi: 10.1109/SOSE.2011.6139107]

[24] Endo AT. Model-Based testing of service oriented applications [Ph.D. Thesis]. Sao Paulo: Universidade de S̃ao Paulo, 2013.

[25] Endo AT, Simao A. Model-Based testing of service-oriented applications via state models. In: Proc. of the IEEE Int'l Conf. on Services Computing (SCC). 2011. 432−439. [doi: 10.1109/SCC.2011.77]

[26] Bernardino M, Rodrigues E, Zorzo A, Marchezan L. An industrial experience on using models to test Web service-oriented applications. In: Proc. of the IET Software. 2017.

[27] Gao H, Li Y. Generating quantitative test cases for probabilistic timed Web service composition. In: Proc. of the APSCC. 2011. 275−283. [doi: 10.1109/APSCC.2011.13]

[28] Cavalli AR, Cao TD, Mallouli W, Martins E, Sadovykh A, Salva S, Zaïdi F. WebMov: A dedicated framework for the modelling and testing of Web services composition. In: Proc. of the Int'l Conf. on Web Services Pages. 2010. 377−384. [doi: 10.1109/ICWS.2010.24]

[29] Zhao H, Sun J, Liu X. A model checking based approach to automatic test suite generation for testing Web services and BPEL. In: Proc. of the IEEE Asia-Pacific Service Computing Conf. 2012. 61−69. [doi: 10.1109/APSCC.2012.29]

[30] Petrova-Antonova D, Ilieva S, Manova D. Tassa: Testing framework for Web service orchestrations.In: Proc. of the 10th IEEE IACM Int'l Workshop on Automation of Software Test. 2015. 8−12. [doi: 10.1109/AST.2015.9]

[31] Cao TD, Felix P, Castanet R. WSOTF: An automatic testing tool for Web services composition. In: Proc. of the 5th Int'l Conf. on Internet and Web Applications and Services (ICIW). 2010. 7−12. [doi: 10.1109/ICIW.2010.9]

[32] Bartolini C, Bertolino A, Marchetti E, Parissis I. Data flow based validation of Web services compositions: Perspectives and examples. In: Proc. of the Architecting Dependable Systems V. LNCS 5135, 2008. 298−325. [doi: 10.1007/978-3-540-85571-2_13]

[33] Zhang J, Yang R, Chen Z. Automated EFSM based test case generation with scatter search. In: Proc. of the 7th Int'l Workshop on AST. 2012. 76−82. [doi: 10.1109/IWAST.2012.6228994]

[34] Gu Y, Ge Y. Search-Based performance testing of applications with composite services. In: Proc. of the 2009 Int'l Conf. on Web Information Systems and Mining (WISM). 2009. 320−324. [doi: 10.1109/WISM.2009.73]

[35] Zhou LB, Xu L, Xu BW, Yang HJ. Generating test cases for composite Web services by parsing XML documents and solving constraints. In: Proc. of the 39th IEEE Annual Int'l Computers, Software & Applications Conf. 2015. 304−309. [doi: 10.1109/COMPSAC.2015.51]

[36] Estero-Botaro A, Garcia-Dominguez A, Dominguez-Jimenez JJ, Palomo-Lozano F, Medina-Bulo I. A framework for genetic test-case generation for WS-BPEL compositions. In: Proc. of the 26th IFIP WG 6.1 Int'l Conf. on Testing Software and Systems (ICTSS). 2014. 1−16. [doi: 10.1007/978-3-662-44857-1_1]

[37] Estero-Botaro A, Palomo-Lozano F, Medina-Bulo I. Quantitative evaluation of mutation operators for WS-BPEL compositions. In: Proc. of the 3rd Int'l Conf. on Software Testing, Verification, and Validation Workshops (ICST). 2010. 142−150. [doi: 10.1109/ICSTW.2010.36]

[38] Dominguez-Jimenez J, Estero-Botaro A, Garcia-Dominguez A, Medina-Bulo I. GAmera: An automatic mutant generation system for WS-BPEL compositions. In: Proc. of the IEEE Int'l Conf. on Web Services. 2009. 97−106. [doi: 10.1109/ECOWS.2009.18]

[39] Casado R, Younas M, Tuya J. A generic framework for testing the Web services transactions. In: Proc. of the Advanced Web Service. 2014. 29−49. [doi: 10.1007/978-1-4614-7535-4_2]

[40] Boonyakulsrirung P, Suwannasart T. A weak mutation testing framework for WS-BPEL. In: Proc. of the 8th Int'l Joint Conf. on Computer Science and Software Engineering (JCSSE). 2011. 313−318. [doi: 10.1109/JCSSE.2011.5930140]

[41] Blanco R, Garcia-Fanjuland J, Tuya J. A first approach to test case generation for BPEL compositions of Web services using scatter search. In: Proc. of the Int'l Conf. on Software Testing, Verification, and Validation Workshops. 2009. 131−140. [doi: 10.1109/ICSTW.2009.24]

[42] Blanco R, Fanjul JG, Tuya J. Test case generation for transition-pair coverage using scatter search. Int'l Journal of Software Engineering and Its Applications, 2010,4(4):37−55.

[43] Li B, Qiu D, Leung H, Wang D. Automatic test case selection for regression testing of composite service based on extensible BPEL flow graph. The Journal of Systems and Software, 2012,85(6):1300−1324. [doi: 10.1016/j.jss.2012.01.036]

[44] Zhang ZY, Chen ZY, Xu BW, Yang R. Research progress on test case evolution. Ruan Jian Xue Bao/Journal of Software, 2013,24(4):663−674 (in Chinese with English abstract). http://www.jos.org.cn/1000-9825/4379.htm [doi: 10.3724/SP.J.1001.2013.04379]

[45] Chen X, Chen JH, Ju XL, Gu Q. Survey of test case prioritization techniques for regression testing. Ruan Jian Xue Bao/Journal of Software, 2013,24(8):1695−1712 (in Chinese with English abstract). http://www.jos.org.cn/1000-9825/4420.htm [doi: 10.3724/SP.J.1001.2013.04420]

[46] Zhang Z, Chan WK, Tse TH. Test case prioritization for regression testing of service-oriented business applications. In: Proc. of the 18th Int'l Conf. on World Wide Web (WWW 2009). 2009. 901−910. [doi: 10.1145/1526709.1526830]

[47] Mei L, Chan WK, Tse TH, Merkel RG. Tag-Based techniques for black-box test case prioritization for service testing. In: Proc. of the 9th Int'l Conf. on Quality Software (QSIC). 2009. 21−30. [doi: 10.1109/QSIC.2009.12]

[48] Mei L, Chan WK, Tse TH, Merkel RG. Merkel. XML-manipulating test case prioritization for XML-manipulating services. Journal of Systems and Software, 2011,84(4):603−619. [doi: 10.1016/j.jss.2010.11.905]

[49] Mei L, Cai Y, Jia C, Jiang B, Chan WK. Prioritizing structurally complex test pairs for validating WS-BPEL evolutions. In: Proc. of the Int'l Conf. Web Service (ICWS). 2013. 147−154. [doi: 10.1109/ICWS.2013.29]

[50] Mei L, Cai Y, Jia C, Jiang B, Zhang Z, Tse YH. A subsumption hierarchy of test case prioritization for composite services. IEEE Trans. on Computing, 2015,8(5):658−673. [doi: 10.1109/TSC.2014.2331683]

[51] Mei L, Zhai K, Jiang B, Chan WK, Tse TH. Preemptive regression test scheduling strategies: A new testing approach to thriving on the volatile service environments. In: Proc. of the IEEE Int'l Conf. Computer Software and Applications. 2012. 901−910. [doi: 10.1109/COMPSAC.2012.17]

[52] Mei L, Zhang Z, Chan WK, Tse TH. Preemptive regression testing of workflow-based Web services. IEEE Trans. on Services Computing, 2015,8(5):740−754. [doi: 10.1109/TSC.2014.2322621]

[53] Wang H, Xing J, Yang Q, Han D, Zhang X. Modification impact analysis based test case prioritization for regression testing of service-oriented workflow applications. In: Proc. of the 39th IEEE Annual Computer Software and Applications Conf. 2015. 288−297. [doi: 10.1109/COMPSAC.2015.11]

[54] Maggie H, Katerina GP. Common trends in software fault and failure data. IEEE Trans. on Software Engineering, 2009,35(4):484−496. [doi: 10.1109/TSE.2009.3]

[55] Zhou YM, Leung H. Empirical analysis of object-oriented design metrics for predicting high and low severity faults. IEEE Trans. on Software Engineering, 2006,32(10):771−789. [doi: 10.1109/TSE.2006.102]

[56] Chen L, Wang Z, Xu L, Lu H, Xu B. Test case prioritization for Web service regression testing. In: Proc. of the 5th IEEE Int'l Symp. on Service Oriented System Engineering (SOSE). 2010. 173−178. [doi: 10.1109/SOSE.2010.27]

[57] Askarunisa A, Abirami AM, Arockia K, Karthik B, Arunkumar R. Sequence-Based techniques for black-box test case prioritization for composite service testing. In: Proc. of the IEEE Int'l Conf. on Computational Intelligence and Computing Research (ICCIC). 2010. 1−4. [doi: 10.1109/ICCIC.2010.5705784]

[58] Hou S, Zhang L, Xie T, Sun JS. Quota-Constrained test-case prioritization for regression testing of service-centric systems. In: Proc. of the IEEE Int'l Conf. on Software Maintenance (ICSM). 2008. 257−266. [doi: 10.1109/ICSM.2008.4658074]

[59] Wang D, Li B, Cai J. Regression testing of composite service: An xbfg-based approach. In: Proc. of the IEEE Congress on Services. 2008. 112−119. [doi: 10.1109/SERVICES-2.2008.28]

[60] Nguyen CD, Marchetto A, Tonella P. Change sensitivity based prioritization for audit testing of Web service compositions. In: Proc. of the 2011 4th IEEE Int'l Conf. on Software Testing, Verification and Validation Workshops. 2011. [doi: 10.1109/ICSTW.2011.50]
[61] Raju S, Uma GV. Factors oriented test case prioritization technique in regression testing using genetic algorithm. European Journal of Scientific Research, 2012,74(3):389−402.
[62] Zhai K, Jiang B, Chan WK. Prioritizing test cases for regression testing of location-based services: Metrics, techniques and case study. IEEE Trans. on Services Computing, 2014,7(1):54−67. [doi: 10.1109/TSC.2012.40]
[63] Harrold MJ, Orso A. Retesting software during development and maintenance. In: Proc. of the Frontiers of Software Maintenance (FoSM). 2008. 99−108. [doi: 10.1109/FOSM.2008.4659253]
[64] Yoo S, Harman M. Using hybrid algorithm for Pareto ecient multi-objective test suite minimisation. Journal of Systems Software, 2010,83(4):689−701. [doi: 10.1016/j.jss.2009.11.706]
[65] Bozkurt M. Cost-Aware Pareto optimal test suite minimisation for service-centric systems. In: Proc. of the 15th Annual Conf. on Genetic and Evolutionary Computation. 2013. 1429−1436.
[66] Tsai WT, Zhou X, Paul R, Chen Y, Bai X. A coverage relationship model for test case selection and ranking for multi-version software. In: Proc. of the 10th IEEE High Assurance Systems Engineering Symp. Dallas: IEEE Computer Society, 2007. 105−112. [doi: 10.1109/HASE.2007.64]
[67] Ruth M, Tu S. Concurrency issues in automating RTS for Web services. In: Proc. of the IEEE Int'l Conf. on Web Services. Salt Lake City, 2007. 1142−1143. [doi: 10.1109/ICWS.2007.65]
[68] Ruth M. Concurrency in a decentralized automatic regression test selection framework for Web services. In: Proc. of the 15th ACM Mardi Gras Conf. 2008. 7:1−7:8.
[69] Tarhini A, Fouchal H, Mansor N. Regression testing Web services-based applications. In: Proc. of the IEEE Int'l Conf. on Computer Systems and Applications. 2006. 163−170. [doi: 10.1109/AICCSA.2006.205085]
[70] Ji SH, Li BX, Zhang PC. Test case selection for data flow based regression testing of BPEL composite services. In: Proc. of the IEEE Int'l Conf. on Services Computing. 2016. 547−554. [doi: 10.1109/SCC.2016.77]
[71] Li B, Qiu D, Ji S, Wang D. Automatic test case selection and generation for regression testing of composite service based on extensible BPEL flow graph. In: Proc. of the 26th IEEE Int'l Conf. on Software Maintenance (ICSM). 2010. 1−10. [doi: 10.1109/ICSM.2010.5609541]
[72] Wang H, Xing J, Yang Q, Wang P, Zhang X. Optimal control based regression test selection for service-oriented workflow applications. Journal of Systems and Software, 2017,124(2017):274−288. [doi: 10.1016/j.jss.2016.06.065]
[73] Cooray MB, Hamlyn-Harris JH, Merkel RG. Test reconfiguration for service oriented applications. In: Proc. of the IEEE Int'l Conf. on Utility Cloud Computing. 2011. 300−305. [doi: 10.1109/UCC.2011.48]
[74] Cooray MB, Hamlyn-Harris JH, Merkel RG. Dynamic test reconfiguration for composite Web services. IEEE Trans. on Services Computing, 2015,8(4):576−585. [doi: 10.1109/TSC.2014.2312953]

附中文参考文献:

[44] 张智轶,陈振宇,徐宝文,杨瑞.测试用例演化研究进展.软件学报,2013,24(4):663−674. http://www.jos.org.cn/1000-9825/4379.htm [doi: 10.3724/SP.J.1001.2013.04379]
[45] 陈翔,陈继红,鞠小林,顾庆.回归测试中的测试用例优先排序技术述评.软件学报,2013,24(8):1695−1712. http://www.jos.org.cn/1000-9825/4420.htm [doi: 10.3724/SP.J.1001.2013.04420]

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