# ComposIT: A Semantic Web Service Composition Engine

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*Abstract*—One major advantage of web services is the ability to be combined to create composite services on-demand through automatic composition techniques. However, although the inclusion of semantics allows a greater precision in the description of their functionality, and therefore greater composition capabilities, the current application of Semantic Web Services (SWS) composition techniques still remains limited due in part to both lack of publicly available, robust, and scalable software composition engines and the heterogeneity that exists among the different SWS description languages. In this paper we introduce ComposIT, a fast and scalable composition engine which is able to automatically compose multiple heterogeneous services from the point of view of the semantic input-output matching thanks to the use of a minimal service model. We also present a complete analysis of two publicly available state-of-the-art composition planners and a comparison between ComposIT and these planners. To carry out this task, we developed a benchmarking tool that automates the evaluation process of the different composition algorithms using an adapted version of the datasets from the Web Service Challenge 2008. Results obtained demonstrate that ComposIT outperforms classical planners both in terms of scalability and performance.

## Purpose of this Web

In previous works[1) 2)], ComposIT was analyzed and compared with the winners of the Web Service Challenge 2008 (WSC'08). These experiments demonstrated that ComposIT can obtain optimal solutions, outperforming the results obtained by the winners with respect to the number of services and the composition length. However, the aim of the experiments presented here is to compare the performance of ComposIT with two open source state-of-the-art composition engines, OWLS-Xplan and PORSCE-II, which use classical AI planning algorithms.

The experimentation is focused on the generation of semantically valid composite services taking into account the semantic information regarding the inputs and outputs of services in absence of preconditions and effects. To carry out this comparison, we developed a benchmarking tool that automates the evaluation process of the different composition algorithms using an adapted version of the WSC'08 datasets. **The purpose of this page is to extend the details of the evaluation explained in the original paper.**

## Datasets

To validate the three composition engines, we used three collections of datasets: Exact-Matching, Semantic-Matching and WSC'08 datasets. The first two collections are based on the original WSC'08 datasets but containing only the services from the solution itself for validation purposes. Characteristics of each dataset are shown below.

### Semantic Matching datasets

Download the XML Semantic-Matching datasets semantic-matching.tar.gz

| Dataset | #Serv | #Serv. Sol. | #Length | Avg. In./Out. | #Init. con. | #Goal con. |
|---|---|---|---|---|---|---|
| Semantic-Matching 01 | 2 | 2 | 2 | 1.0 / 1.0 | 1 | 1 |
| Semantic-Matching 02 | 3 | 3 | 2 | 3.0 / 1.0 | 3 | 1 |
| Semantic-Matching 03 | 10 | 10 | 3 | 4.03 / 3.08 | 3 | 2 |
| Semantic-Matching 04 | 5 | 5 | 3 | 4.25 / 4.68 | 4 | 1 |
| Semantic-Matching 05 | 40 | 40 | 23 | 5.07 / 2.44 | 3 | 1 |
| Semantic-Matching 06 | 10 | 10 | 5 | 5.47 / 3.47 | 6 | 4 |
| Semantic-Matching 07 | 20 | 20 | 8 | 3.03 / 5.11 | 2 | 3 |
| Semantic-Matching 08 | 35 | 35 | 14 | 3.10 / 3.37 | 9 | 4 |
| Semantic-Matching 09 | 20 | 20 | 12 | 3.07 / 4.40 | 8 | 1 |
| Semantic-Matching 10 | 30 | 30 | 20 | 3.25 / 5.42 | 5 | 4 |

### Exact Matching datasets

Download the XML Exact-Matching datasets exact-matching.tar.gz

| Dataset | #Serv | #Serv. Sol. | #Length | Avg. In./Out. | #Init. con. | #Goal con. |
|---|---|---|---|---|---|---|
| Exact-Matching 01 | 2 | 2 | 2 | 1.0 / 1.0 | 1 | 2 |
| Exact-Matching 02 | 3 | 3 | 2 | 3.0 / 20.5 | 3 | 40 |
| Exact-Matching 03 | 10 | 10 | 3 | 4.03 / 16.53 | 3 | 100 |
| Exact-Matching 04 | 5 | 5 | 3 | 4.25 / 21.05 | 4 | 77 |
| Exact-Matching 05 | 40 | 40 | 23 | 5.07 / 14.20 | 3 | 407 |
| Exact-Matching 06 | 10 | 10 | 5 | 5.47 / 24.09 | 6 | 157 |
| Exact-Matching 07 | 20 | 20 | 8 | 3.03 / 26.39 | 2 | 261 |
| Exact-Matching 08 | 35 | 35 | 14 | 3.10 / 23.21 | 9 | 507 |
| Exact-Matching 09 | 20 | 20 | 12 | 3.07 / 24.71 | 8 | 219 |
| Exact-Matching 10 | 30 | 30 | 20 | 3.25 / 33.81 | 5 | 473 |

### Web Service Challenge 2008 datasets

Download the XML WSC'08 datasets wsc08.tar.gz

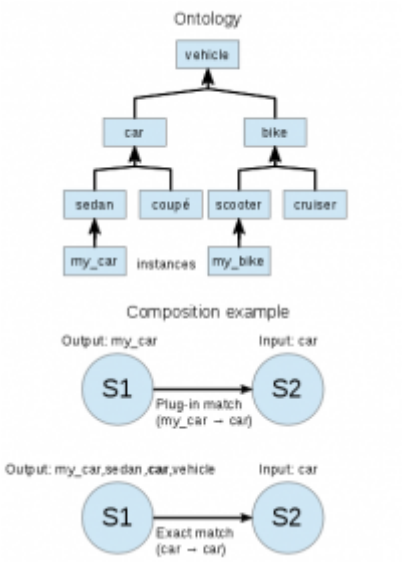
Download the XML WSC'08 datasets with taxonomy.xml ontologies converted to OWL wsc08.zip

| Dataset | #Serv | #Serv. Sol. | #Length | Avg. In./Out. | #Init. con. | #Goal con. |
|---|---|---|---|---|---|---|
| WSC'08 01 | 158 | 10 | 3 | 3.53 / 5.25 | 3 | 1 |
| WSC'08 02 | 558 | 5 | 3 | 3.79 / 3.92 | 4 | 1 |
| WSC'08 03 | 604 | 40 | 23 | 4.07 / 6.46 | 3 | 2 |
| WSC'08 04 | 1041 | 10 | 5 | 4.23 / 5.47 | 6 | 1 |
| WSC'08 05 | 1090 | 20 | 8 | 3.36 / 4.26 | 2 | 1 |
| WSC'08 06 | 2198 | 35 | 14 | 6.00 / 4.31 | 9 | 4 |
| WSC'08 07 | 4113 | 20 | 12 | 7.37 / 7.21 | 8 | 3 |

| Dataset | #Serv | #Serv. Sol. | #Length | Avg. In./Out. | #Init. con. | #Goal con. |
|---|---|---|---|---|---|---|
| WSC'08 08 | 8119 | 30 | 20 | 5.44 / 6.54 | 5 | 4 |

Exact-Matching datasets were calculated by extending the outputs of each web service, including all superclasses of each output as an output of the service itself (semantic expansion). Thus, the average number of outputs is bigger than in the other datasets. The semantic expansion transforms a semantic matching problem into a exact matching problem, when exact and plug-in match is used to perform the semantic matchmaking. This allows us to test composition algorithms (that do not use semantic reasoners) with the WSC'08 datasets. For example, suppose that a service S1 provides the instance “my_car” which is an instance of the concept “sedan”, whereas another service S2 requires an input “car”. Given that “my_car” is a sedan “car” (plug-in match), S2 can use it as an input. This behavior can be simulated by adding superclasses of “my_car” to the service. Thus, service S1 will return outputs “my_car”, “car”, “sedan” and “vehicle” after the semantic expansion.

The next figure represents an example of the semantic expansion. In the first case, a semantic reasoner is required to match output “my_car” to “car”. In the second case, the service returns the output “my_car” as well as all superclasses (sedan, car, vehicle). In this case, the output “car” from S1 matches exactly the input “car” from S2.




# Evaluation

The performance of each composition algorithm has been measured using a test platform developed for this purpose. We carried out three different experiments, one for each collection of datasets shown in the previous tables, to determine the quality of the solutions and the composition time. The experiments consisted of five independent executions of each algorithm over each dataset. The number of services and the length of the composition, as well as the minimum, average and standard deviation of the time taken to solve the composition problem are shown in the tables below. All the experiments were performed using a Windows XP 32-bit with VirtualBox 4.1.22 (2 GB of RAM, 1 core), on a PC-station equipped with an Intel Core 2 Quad Q9550 at 2.83GHz running Ubuntu 10.04 64-bit.

### 1. Exact-Matching evaluation results

| Dataset | Algorithm | Solution | | Execution (ms) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | #Serv | #Length | Ex. 1 | Ex. 2 | Ex. 3 | Ex. 4 | Ex.5 | Min | Avg | SD |
| Exact-Matching 01 | ComposIT | 2 | 2 | 238.20 | 158.04 | 153.63 | 153.61 | 145.07 | 145.07 | 169.71 | 38.57 |
| | Xplan | 2 | 2 | 306.65 | 348.32 | 328.53 | 359.50 | 305.37 | 305.37 | 329.67 | 24.29 |
| | PORSCE-II | 2 | 2 | 3478.53 | 3717.59 | 3657.99 | 3524.25 | 3553.97 | 3478.53 | 3586.47 | 98.60 |
| Exact-Matching 02 | ComposIT | 3 | 2 | 274.59 | 209.04 | 211.42 | 196.24 | 206.73 | 196.24 | 219.60 | 31.28 |
| | Xplan | 3 | 3 | 416.11 | 490,68 | 391.30 | 476.10 | 422.66 | 391.30 | 439.37 | 42.17 |
| | PORSCE-II | 9 | 9 | 5206.54 | 5283.59 | 5240.02 | 5482.74 | 5649.92 | 5206.54 | 5372.56 | 188.49 |
| Exact-Matching 03 | ComposIT | 10 | 3 | 422.66 | 379.86 | 369.33 | 330.27 | 365.57 | 330.27 | 373.54 | 33.19 |
| | Xplan | 10 | 10 | 815.73 | 642.90 | 616.80 | 595.58 | 622.55 | 595.58 | 658.71 | 89.38 |
| | PORSCE-II | 22 | 22 | 16081.13 | 15721.06 | 15105.77 | 16452.69 | 14779.84 | 14779.84 | 15628.10 | 686.69 |
| Exact-Matching 04 | ComposIT | 5 | 3 | 321.52 | 316.63 | 316.42 | 354.47 | 381.93 | 316.42 | 338.19 | 29.13 |
| | Xplan | - | - | - | - | - | - | - | - | - | - |
| | PORSCE-II | 14 | 14 | 10889.68 | 10777.27 | 10595.46 | 10898.34 | 10767.12 | 10595.46 | 10785.57 | 122.58 |
| Exact-Matching 05 | ComposIT | 40 | 23 | 7111.35 | 6676.08 | 6669.89 | 6775.57 | 6710.47 | 6669.89 | 6788.67 | 185.20 |
| | Xplan | - | - | - | - | - | - | - | - | - | - |
| | PORSCE-II | - | - | - | - | - | - | - | - | - | - |
| Exact-Matching 06 | ComposIT | 10 | 5 | 463.92 | 468.82 | 603.30 | 484.27 | 505.79 | 463.92 | 505.22 | 57.20 |
| | Xplan | - | - | - | - | - | - | - | - | - | - |
| | PORSCE-II | 27 | 27 | 24106.72 | 24340.28 | 23880.96 | 24732.57 | 24025.89 | 23880.96 | 24217.28 | 332.65 |
| Exact-Matching 07 | ComposIT | 20 | 8 | 952.07 | 1103.62 | 951.09 | 1015.01 | 895.89 | 895.89 | 983.54 | 79.27 |
| | Xplan | - | - | - | - | - | - | - | - | - | - |
| | PORSCE-II | 52 | 52 | 38036.12 | 37755.37 | 35577.92 | 36377.60 | 36306.59 | 35577.92 | 36810.72 | 1043.49 |
| Exact-Matching 08 | ComposIT | 35 | 14 | 6071.00 | 6299.35 | 5859.83 | 6324.65 | 6174.44 | 5859.83 | 6145.85 | 189.58 |
| | Xplan | - | - | - | - | - | - | - | - | - | - |
| | PORSCE-II | - | - | - | - | - | - | - | - | - | - |
| Exact-Matching 09 | ComposIT | 20 | 12 | 1079.93 | 1065.36 | 1096.51 | 1090.66 | 1100.17 | 1065.36 | 1086.53 | 14.09 |
| | Xplan | - | - | - | - | - | - | - | - | - | - |
| | PORSCE-II | - | - | - | - | - | - | - | - | - | - |
| Exact-Matching 10 | ComposIT | 30 | 20 | 5236.27 | 5596.29 | 5352.37 | 5663.87 | 5263.09 | 5236.27 | 5422.38 | 195.88 |
| | Xplan | - | - | - | - | - | - | - | - | - | - |
| | PORSCE-II | - | - | - | - | - | - | - | - | - | - |

## 2. Semantic-Matching evaluation results

Results of the semantic analysis done to detect the optimal values of the thresholds for PORSCE-II.

| Plug-in threshold | Time (for Semantic-Matching 01) | % Datasets solved | Semantic-Matching datasets solved | Performance |
|---|---|---|---|---|
| 1 | 6721.69 | 10% | 01 | 100.00% |
| 2 | 9735.35 | 30% | 01, 02, 03 | 69.04% |
| 3 | 13257.96 | 40% | 01, 02, 03, 04 | 50.70% |
| 4 | 15139.06 | 50% | 01, 02, 03, 04, 07 | 44.40% |
| 5 | 20059.98 | 50% | 01, 02, 03, 04, 07 | 33.51% |
| 6 | 20616.51 | 60% | 01, 02, 03, 04, 06, 07 | 32.60% |
| 7 | 24607.99 | 60% | 01, 02, 03, 04, 06, 07 | 27.32% |
| 8 | 27791.03 | 60% | 01, 02, 03, 04, 06, 07 | 24.19% |
| 9 | 31261.37 | 60% | 01, 02, 03, 04, 06, 07 | 21.50% |
| 10 | 33648.79 | 60% | 01, 02, 03, 04, 06, 07 | 19.98% |
| 11 | 34074.82 | 60% | 01, 02, 03, 04, 06, 07 | 19.73% |
| 12 | 40787.78 | 60% | 01, 02, 03, 04, 06, 07 | 16.48% |
| 13 | 40704.43 | 60% | 01, 02, 03, 04, 06, 07 | 16.51% |

| Plug-in threshold | Time (for Semantic-Matching 01) | % Datasets solved | Semantic-Matching datasets solved | Performance |
|---|---|---|---|---|
| 14 | 44085.17 | 60% | 01, 02, 03, 04, 06, 07 | 15.25% |
| 15 | 47256.00 | 60% | 01, 02, 03, 04, 06, 07 | 14.22% |
| 16 | 50164.25 | 60% | 01, 02, 03, 04, 06, 07 | 13.40% |
| 17 | 51815.99 | 60% | 01, 02, 03, 04, 06, 07 | 12.97% |
| 18 | 56561.49 | 60% | 01, 02, 03, 04, 06, 07 | 11.88% |
| 19 | 58981.02 | 60% | 01, 02, 03, 04, 06, 07 | 11.40% |

Based on these results, we selected the following optimal threshold *N* for each datasets: *N=1* for *Semantic-Matching 01*, *N=2* for *Semantic-Matching 02* and *03*, *N=3* for *Semantic-Matching 04*, *N=4* for *Semantic-Matching 07* and *N=6* for *Semantic-Matching 06*.

| Dataset | Algorithm | Solution | | Execution (ms) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | #Serv | #Length | Ex. 1 | Ex. 2 | Ex. 3 | Ex. 4 | Ex.5 | Min | Avg | SD |
| Semantic-Matching 01 | ComposIT | 2 | 2 | 92.46 | 214.92 | 108.11 | 297.97 | 387.13 | 92.46 | 220.12 | 125.32 |
| | PORSCE-II (1) | 2 | 2 | 7487.74 | 6655.72 | 6537.85 | 6190.85 | 8326.61 | 6190.85 | 7039.75 | 862.66 |
| Semantic-Matching 02 | ComposIT | 3 | 2 | 272.64 | 387.46 | 119.45 | 87.49 | 240.80 | 87.49 | 221.57 | 121.35 |
| | PORSCE-II (2) | 3 | 3 | 14355.59 | 14784.66 | 14467.15 | 13685.42 | 14779.62 | 13685.42 | 14414.49 | 449.48 |
| Semantic-Matching 03 | ComposIT | 10 | 3 | 104.14 | 261.09 | 229.25 | 307.21 | 317.30 | 104.14 | 243.80 | 85.79 |
| | PORSCE-II (2) | 11 | 11 | 47524.98 | 49847.54 | 49750.68 | 45989.71 | 45359.04 | 45359.04 | 47694.39 | 2076.83 |
| Semantic-Matching 04 | ComposIT | 5 | 3 | 287.12 | 213.46 | 97.21 | 112.70 | 101.86 | 97.21 | 162.47 | 84.48 |
| | PORSCE-II (3) | 7 | 7 | 29187.01 | 29593.40 | 29466.08 | 28759.73 | 31130.29 | 28759.73 | 29627.30 | 898.98 |
| Semantic-Matching 05 | ComposIT | 40 | 23 | 684.00 | 694.36 | 682.87 | 272.57 | 282.76 | 272.57 | 523.31 | 224.32 |
| | PORSCE-II (16) | - | - | - | - | - | - | - | - | - | - |
| Semantic-Matching 06 | ComposIT | 10 | 5 | 223.73 | 409.05 | 101.80 | 96.48 | 125.48 | 96.48 | 191.31 | 132.10 |
| | PORSCE-II (6) | 14 | 14 | 134258.53 | 114729.94 | 112889.12 | 114402.36 | 118113.16 | 112889.12 | 118878.62 | 8806.96 |
| Semantic-Matching 07 | ComposIT | 20 | 8 | 332.64 | 402.18 | 178.90 | 132.44 | 342.98 | 132.44 | 277.83 | 115.80 |
| | PORSCE-II (4) | 35 | 35 | 154651.56 | 155128.96 | 153448.76 | 156402.12 | 153196.42 | 153196.42 | 154565.56 | 1305.71 |
| Semantic-Matching 08 | ComposIT | 35 | 14 | 674.44 | 742.30 | 857.37 | 338.21 | 790.32 | 338.21 | 680.53 | 202.71 |
| | PORSCE-II (17) | - | - | - | - | - | - | - | - | - | - |
| Semantic-Matching 09 | ComposIT | 20 | 12 | 445.83 | 295.22 | 151.83 | 180.21 | 684.96 | 151.83 | 351.61 | 219.36 |
| | PORSCE-II (15) | - | - | - | - | - | - | - | - | - | - |
| Semantic-Matching 10 | ComposIT | 30 | 20 | 219.66 | 214.97 | 445.83 | 535.24 | 210.08 | 210.08 | 325.16 | 154.28 |
| | PORSCE-II (17) | - | - | - | - | - | - | - | - | - | - |

## 3. WSC'08 evaluation results

| Dataset | Algorithm | Solution | | Execution (ms) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | #Serv | #Length | Ex. 1 | Ex. 2 | Ex. 3 | Ex. 4 | Ex.5 | Min | Avg | SD |
| WSC'08 01 | ComposIT | 10 | 3 | 308.45 | 223.35 | 224.23 | 217.05 | 231.03 | 217.05 | 240.82 | 38.13 |
| | PORSCE-II (2) | 11 | 11 | 700552.14 | 703166.16 | 706210.96 | 709269.96 | 688332.37 | 688332.37 | 701506.32 | 8056.46 |
| WSC'08 02 | ComposIT | 5 | 3 | 286.18 | 247.79 | 236.50 | 231.01 | 308.12 | 231.01 | 261.92 | 33.63 |
| | PORSCE-II (3) | 8 | 8 | 3633027.68 | 3635780.31 | 3494138.55 | 3518414.74 | 3501751.84 | 3494138.55 | 3556622.62 | 71551.69 |
| WSC'08 03 | ComposIT | 40 | 23 | 1448.94 | 1417.31 | 1429.48 | 1413.16 | 1457.06 | 1413.16 | 1433.19 | 19.27 |
| | PORSCE-II (16) | - | - | - | - | - | - | - | - | - | - |
| WSC'08 04 | ComposIT | 10 | 5 | 427.54 | 434.77 | 434.53 | 451.68 | 440.62 | 427.54 | 437.83 | 9.02 |
| | PORSCE-II (6) | 16 | 16 | 13594552.10 | 13746460.11 | 13260928.67 | 13153932.78 | 13152705.66 | 13152705.66 | 13381715.86 | 272606.85 |

| Dataset | Algorithm | Solution | | Execution (ms) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | #Serv | #Length | Ex. 1 | Ex. 2 | Ex. 3 | Ex. 4 | Ex.5 | Min | Avg | SD |
| WSC'08 05 | ComposIT | 20 | 8 | 1052.68 | 1018.33 | 995.83 | 1019.80 | 1011.26 | 995.83 | 1019.58 | 20.80 |
| | PORSCE-II (4) | 45 | 45 | 9569454.60 | 9642162.17 | 9461697.18 | 9900376.49 | 9735598.82 | 9461697.18 | 9661857.85 | 166822.85 |
| WSC'08 06 | ComposIT | 42 | 7 | 3611.03 | 3587.10 | 3525.84 | 3535.71 | 3436.85 | 3436.85 | 3539.31 | 67.31 |
| | PORSCE-II (17) | - | - | - | - | - | - | - | - | - | - |
| WSC'08 07 | ComposIT | 20 | 12 | 4164.99 | 4043.20 | 4083.13 | 4062.16 | 4095.46 | 4043.20 | 4089.79 | 46.54 |
| | PORSCE-II (15) | - | - | - | - | - | - | - | - | - | - |
| WSC'08 08 | ComposIT | 30 | 20 | 5849.57 | 5751.64 | 5962.46 | 5740.37 | 5710.24 | 5710.24 | 5802.86 | 103.39 |
| | PORSCE-II (17) | - | - | - | - | - | - | - | - | - | - |

You can download the validation logs for each algorithm here:

- ComposIT Exact-Matching/Semantic-Matching/WSC'08 logs (download)
- PORSCE-II Exact-Matching/Semantic-Matching/WSC'08 logs (download)
- OWLS-Xplan Exact-Matching logs (download)

# Usage

We provide three different java binaries for each composition algorithm. In order to launch a test, you must have installed the Java JDK 6+. Latest java JDK is available here. Once installed, you can run the test platform in GUI mode or in console mode. To launch the GUI interface, simply type:

```
java -jar algorithm.jar
```

Where algorithm.jar is one of the available algorithms:

- ComposIT: CompositAlgorithm.jar (download)
- PORSCE-II: PorsceAlgorithm.jar (download)
- OWLS-Xplan: OWLSXplanAlgorithm.jar (download)

These versions of the OWLS-Xplan and PORSCE-II were modified to support the integration with the test platform. Original versions of these algorithms can be downloaded here:

- PORSCE-II: http://www.dit.hua.gr/~raniah/research.html
- OWLS-Xplan 2.0: http://projects.semwebcentral.org/projects/owls-xplan/

You can launch also a background test from the command line, with the following syntax:

```
java -jar algorithm.jar algorithm_name dataset_path http_server_port
```

Examples to launch tests on each repository with the dataset Exact-Matching 01, using the port 80 to create the http server to provide the services and redirecting the output to a file 01.txt:

ComposIT:

```
java -Xmx1024M -Xms512M -jar CompositAlgorithm.jar "ComposIT"
"...\Datasets\Exact-matching\01" 80 > 01.txt
```

PORSCE-II:

```
java -Xmx1024M -Xms512M -jar PorsceAlgorithm.jar "PORSCE-II"
"...\Datasets\Exact-matching\01" 80 > 01.txt
```

OWLS-Xplan:

```
java -Xmx1024M -Xms512M -jar OWLSXplanAlgorithm.jar "OWL-S Xplan 2.0"
"...\Datasets\Exact-matching\01" 80 > 01.txt
```

# Disclaimer

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1)
P. Rodriguez-Mier, M. Mucientes, and M. Lama, “Automatic Web Service Composition with a Heuristic-Based Search Algorithm,” in *International Conference on Web Services (ICWS)*. IEEE Computer Society, 2011, pp. 81–88.
2)
P. Rodriguez-Mier, M. Mucientes, J. Vidal, and M. Lama, “An optimal and complete algorithm for automatic web service composition,” *International Journal of Web Services Research (IJWSR)*, vol. 9, no. 2, pp. 1–20, 2012.