Service Reliability Engineering: Performance Evaluation, Fault Tolerance, and Reliability Prediction

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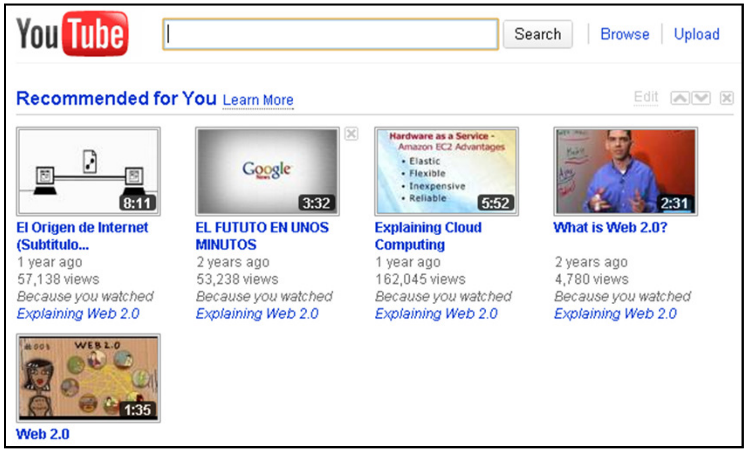
Outline

- Introduction
- Performance evaluation of Web services
- Fault-tolerant Web services
- Reliability prediction of Web services
- Conclusion

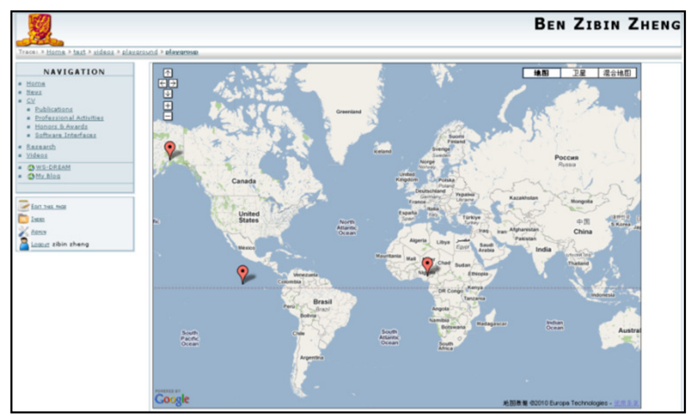
Introduction

Web applications are becoming more and more important!



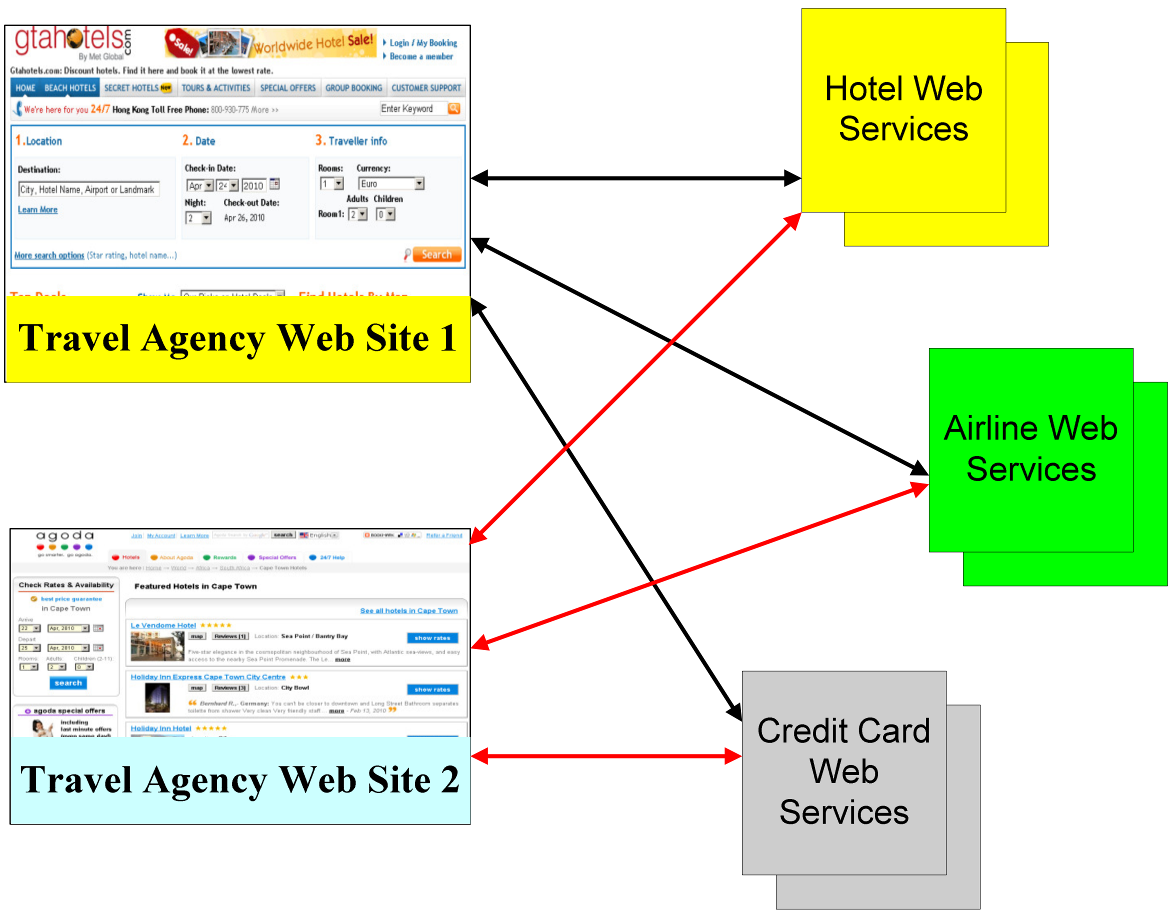
Introduction

- The age of Web 2.0
  - Web pages and Web services
- Web services (WS) are Web APIs that can be accessed over a network and executed on remote systems
  - Open standards
  - Interoperability



Introduction

- Service-oriented systems
  - Composed by distributed Web services



Fault Lifecycle Technique

Fault Manifestation and Modeling Process

Reliability

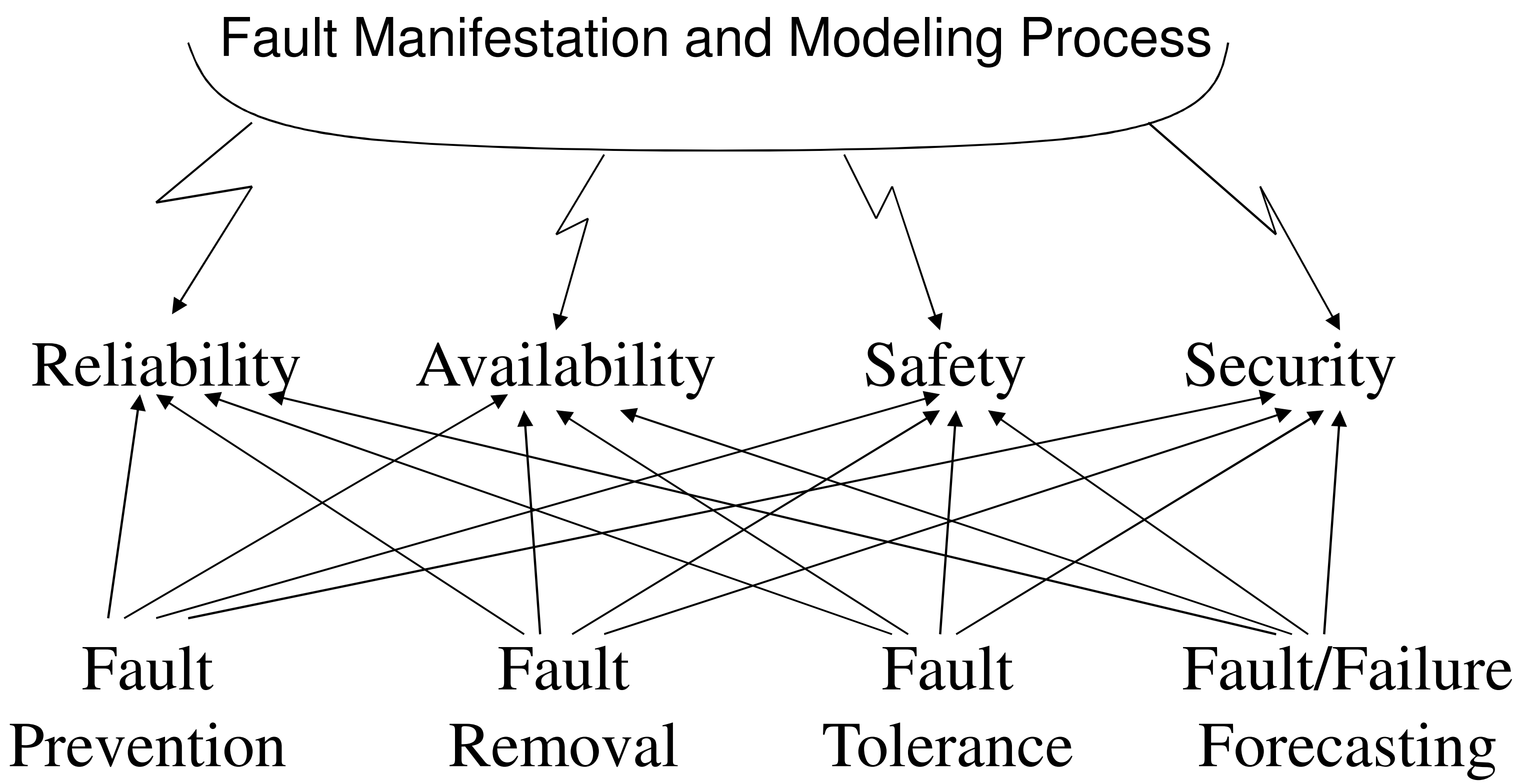
Fault Prevention

Fault Removal

Fault Tolerance

Fault/Failure Forecasting

Fault Lifecycle Technique



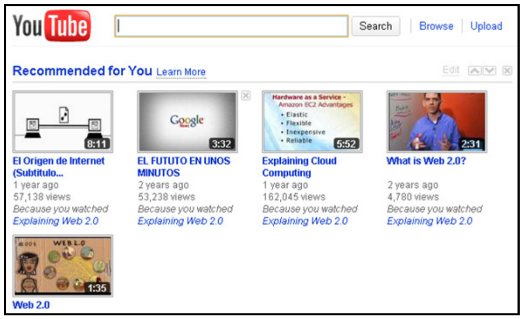
Building Reliable Service-oriented Systems

- It is difficult to build reliable service-oriented systems
  - Reliability of the system is highly dependent on the invoked Web services
  - Web services are provided by other organizations
  - The Internet environment is unpredictable
- Approaches for building reliable service-oriented systems
  - Fault prevention
  - Fault removal
  - Fault tolerance
  - Fault prediction

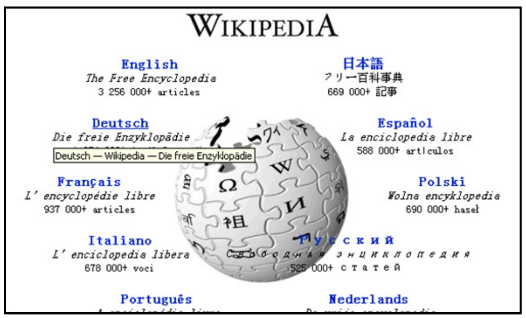
To provide real-world research data:
Performance Evaluation

Part 1: Performance Evaluation of Web Services

User-Collaboration

- 

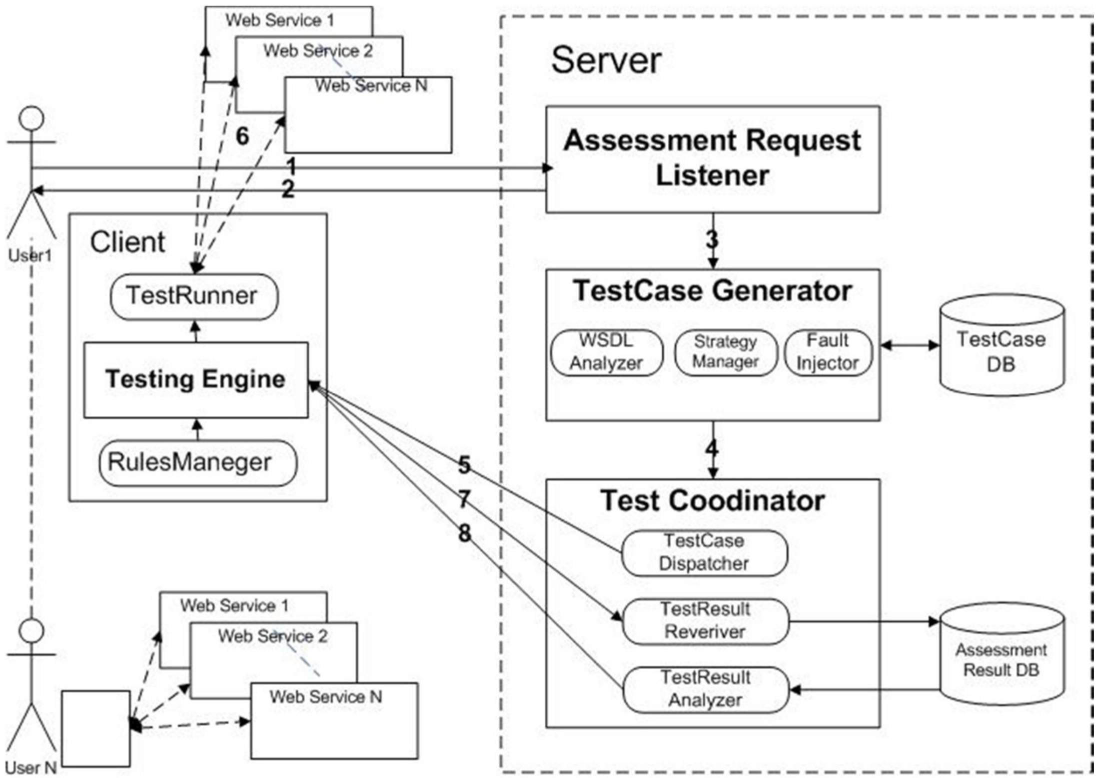
  Users contribute videos

- 

  Users contribute knowledge

- WS Evaluation: users contribute evaluation results of Web services

Distributed Evaluation Framework



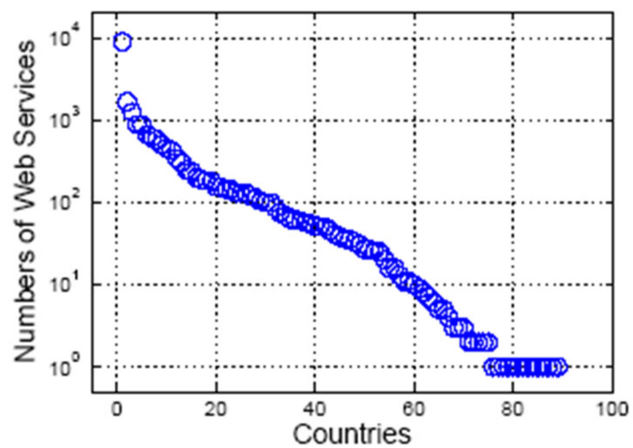
1. Evaluation request
2. Load Applet
3. Create test cases
4. Schedule test tasks
5. Assign test cases
6. Client run test cases
7. Send back results
8. Analyze and return final results to client.

- Evaluation results from different locations
- No need good knowledge on Web service evaluation
- No need to implement evaluation mechanism

Location Information

- 21,358 Web services from 89 countries
- The top 3 countries provide 55.5% of the obtained Web services
  - United States: 8867 Web services
  - United Kingdom: 1657 Web services
  - Germany: 1246 Web services

Locations of Web Services

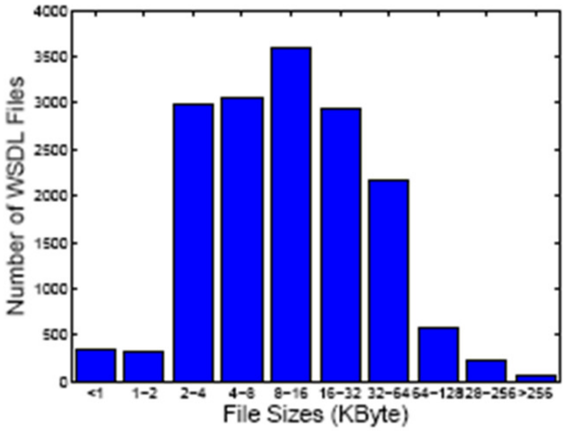


Distributions of Web Services

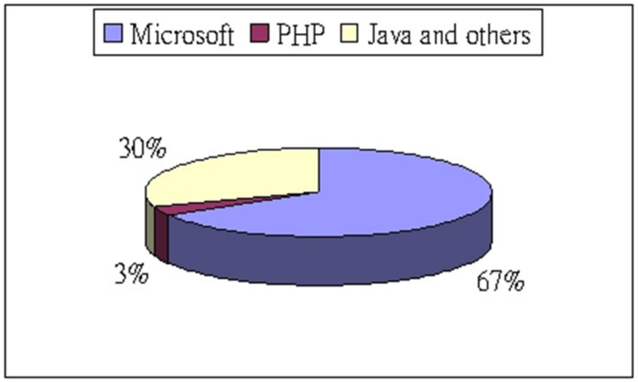
WSDL File Information

WSDL File Obtaining Failures

Code	Description	# WS	Percent
400	Bad Request	173	3.57%
401	Unauthorized	106	2.19%
403	Forbidden	153	3.16%
404	File Not Found	1468	30.31%
405	Method Not Allowed	1	0.02%
500	Internal Server Error	505	10.43%
502	Bad Gateway	51	1.05%
503	Service Unavailable	22	0.45%
504	Gateway Timeout	788	16.27%
505	HTTP Version Not Support	1	0.02%
N/A	Connection Timed Out	774	15.98%
N/A	Read Timed Out	787	16.25%
N/A	Unknown Host	12	0.25%
N/A	Redirected Too Many Times	3	0.06%
Total		4844	100.00%



Distributions of WSDL File Sizes



Development Technologies

Java Code Generation

- Axis 2 to generate Java codes for the Web services.
- Totally 235,262,555 lines of Java codes are produced.

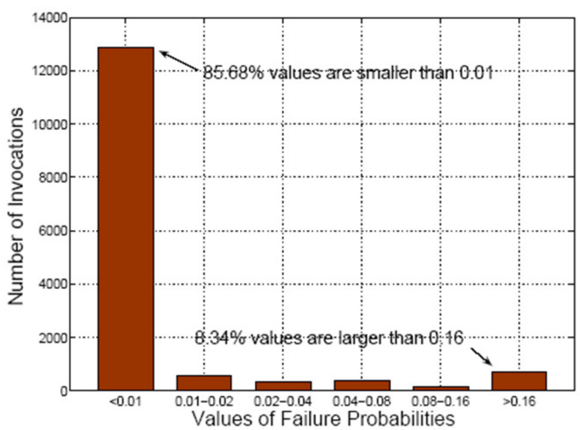
Java Code Generation Failures

Failure Type	# WS	Percent
Empty File	249	7.31%
Invalid File Format	1232	36.17%
Error Parsing WSDL	1135	33.32%
Invocation Target Exception	764	22.43%
Null QName	22	0.65%
Databinding Unmatched Type Exception	4	0.12%
Total	3406	100%

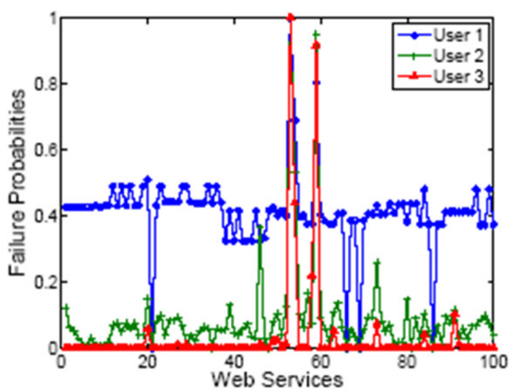
Dataset 1: 150*100*100

Statistics of the Dataset 1

Statistics	Values
Num. of Web Service Invocations	1,542,884
Num. of Service Users	150
Num. of Web Services	100
Num. of User Countries	24
Num. of Web Service Countries	22
Range of Failure Probability	0-100%
Mean of Failure Probability	4.05%
Standard Deviation of Failure Probability	17.32%



Distribution of Failure Probabilities



Three Users' Failure Probabilities

Failure Types

(1) Web service invocations can fail easily.

(2) WS invocation failures are unavoidable in the unpredictable Internet.

(3) Service fault tolerance approaches are becoming important.

Failures of the Dataset 1

Descriptions	Number
(400)Bad Request	3
(500)Internal Server Error	26
(502)Bad Gateway	33
(503)Service Unavailable	609
java.net.SocketException: Network is unreachable	3
java.net.SocketException: Connection reset	1175
java.net.NoRouteToHostException: No route to host	415
java.net.ConnectException: Connection refused	619
java.net.SocketTimeoutException: Read timed out	4606
java.net.UnknownHostException	5847
java.net.SocketTimeoutException: Connect timed out	44809
Other errors	39
Total	58184

Dataset 2: 339*5825*1

Statistics of the Dataset 2

Statistics	Values
Num. of Web Service Invocations	1,974,675
Num. of Service Users	339
Num. of Web Services	5,825
Num. of User Countries	30
Num. of Web Service Countries	73
Mean of Response Time	1.43 s
Standard Deviation of Response Time	31.9 s
Mean of Throughput	102.86 kbps
Standard Deviation of Throughput	531.85 kbps

(a) Locations of Service Users

(b) Locations of Web Services

Dataset Publication

- The evaluation results are released at: http://www.wsdream.net
- Downloaded about 100 times by more than 50 universities (or research institutes) from more than 15 counties.
- The datasets can be used in research topics of:
  - Web service selection and composition
  - Web service recommendation
  - Web service QoS prediction
  - Fault-tolerant Web services
  - …………………
- The largest-scale real-world Web service QoS evaluation
- Recognized by the Best Student Paper of ICWS2010

Part 2: Fault-Tolerant Web Services

Fault-Tolerant Web Services

- It is difficult to build reliable service-oriented systems.
  - Reliability of the system is highly dependent on the remote Web service components.
  - Web services are usually hosted by other organizations.
    - May contain faults
    - May become unavailable suddenly
    - Source codes of the Web services are usually unavailable
  - The Internet environment is unpredictable.

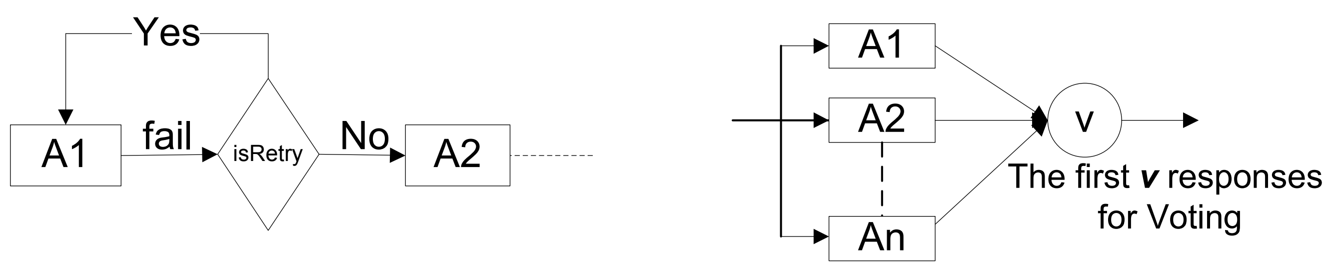
How to employ the redundant Web services and their QoS values for building fault-tolerant service-oriented systems?

Adaptive Fault Tolerance

- Internet environment is highly dynamic
  - Network condition changes
  - Software/hardware updates of the Web services
  - Server workload changes
- Traditional fault tolerance strategies are too static
  - Fixed at design time
  - Cannot adaptive to the dynamic environment

Adaptive Fault Tolerance

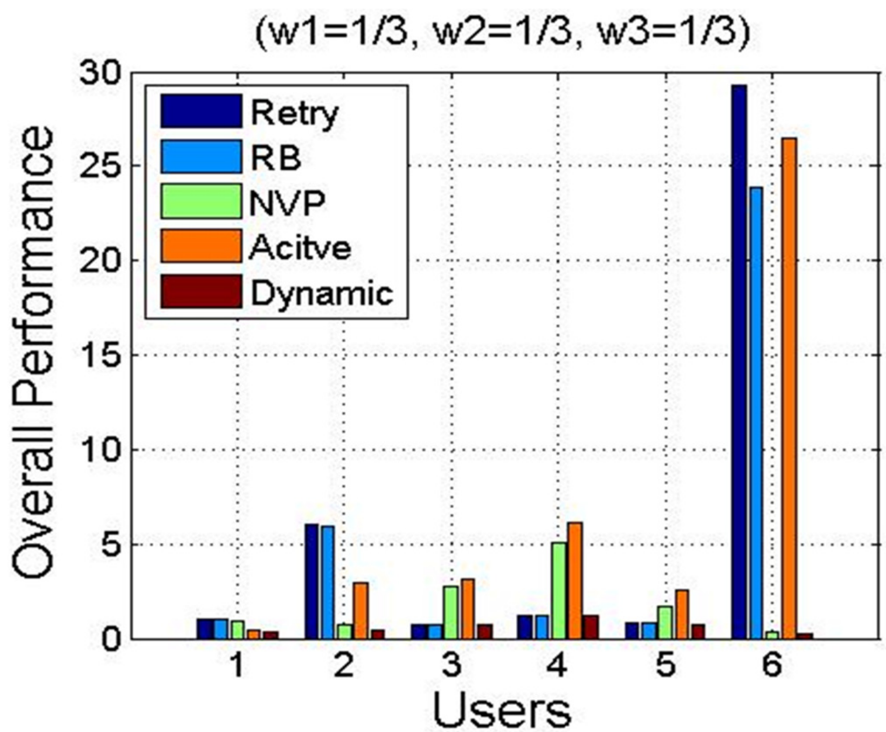
- Idea: determine optimal fault tolerance strategy dynamically at runtime based on the Web service QoS values.



(1). Dynamic Sequential Strategy

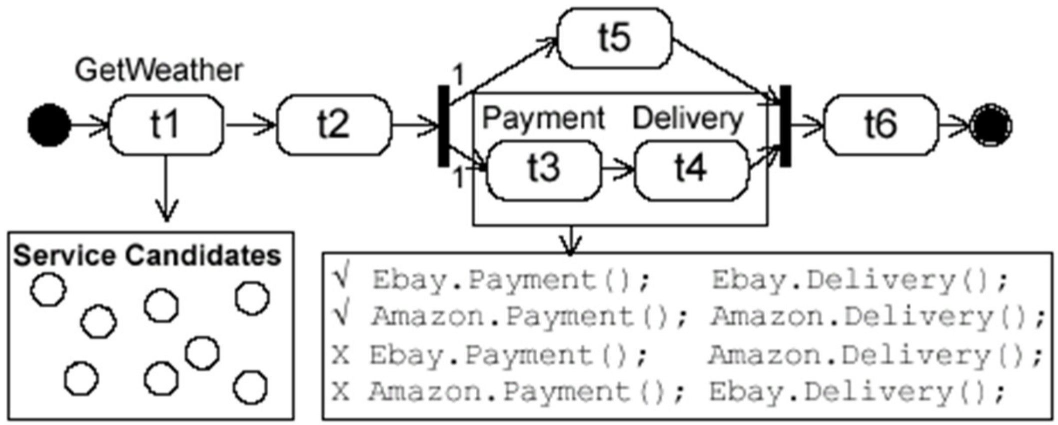
(2). Dynamic Parallel Strategy

Adaptive Fault Tolerance



- Static fault tolerance strategies have good performance in some cases, but have bad performance in others.
- The proposed strategy obtains the best overall performance for all the six users.

Fault-Tolerant Framework



- Target:
  - Optimal FT strategy selection for each task under local and global constraints
- Local constraint: Response time of t1 < 1000 ms
- Global constraint: Success-rate of the whole service plan > 99%

Fault-Tolerant Framework

- 0-1 Integer Programming Problem

Problem 2: **Minimize:**

$$\sum_{i \in ER_i} \sum_{j \in S_i} u_{ij} x_{ij}$$

Subject to:

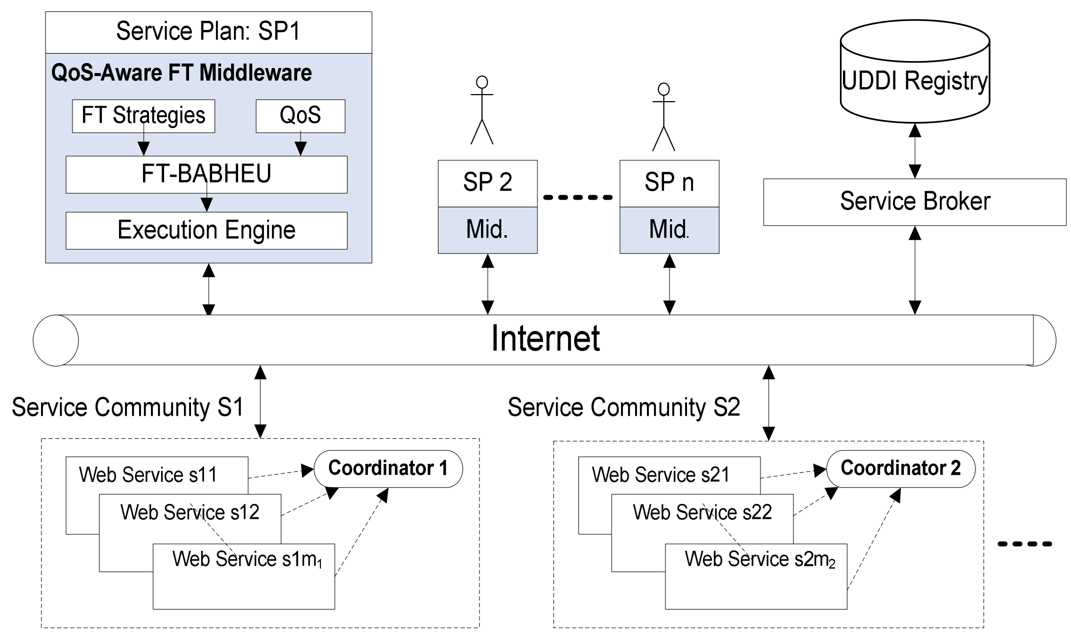
$$\sum_{i \in ER_i} \sum_{j \in S_i} q_{ij}^y x_{ij} \le gc^y (y = 2, 3, 4)$$

$$\forall k, \sum_{i \in SR_{ik}} \sum_{j \in S_i} q_{ij}^y x_{ij} \le gc^y (y = 6, 8)$$

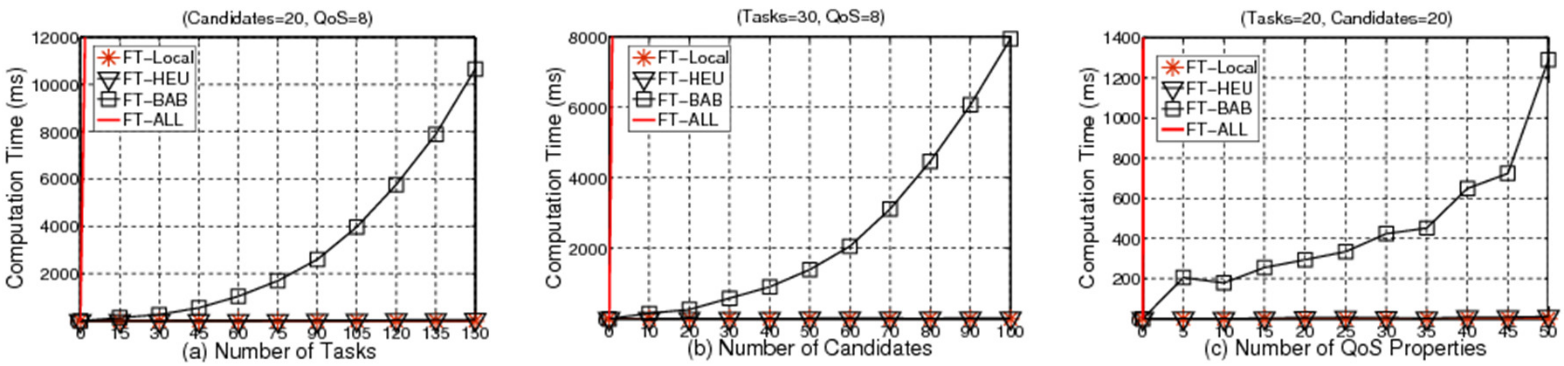
$$\prod_{i \in ER_i} \prod_{j \in S_i} (q_{ij}^y)^{x_{ij}} \le gc^y (y = 1, 5, 7)$$

$$\forall SFT_i, x_{y_1 j} = x_{y_2 j} = ... = x_{y_{n_i} j} (t_{y_i} \in SFT_i)$$

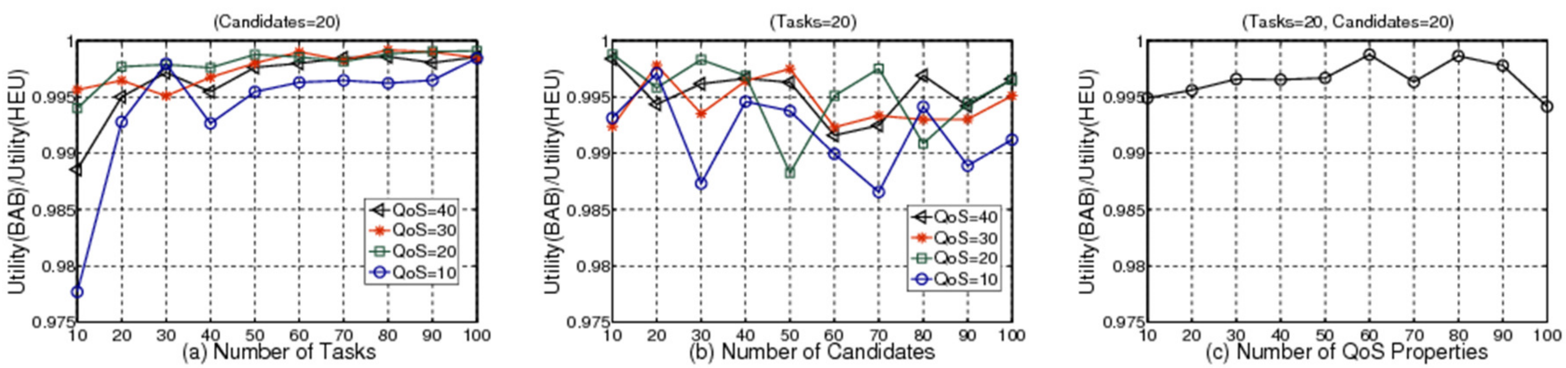
$$\forall i, \sum_{j \in S_i} x_{ij} = 1; x_{ij} \in \{0, 1\}$$



Fault-Tolerant Framework



Performance of Computation Time

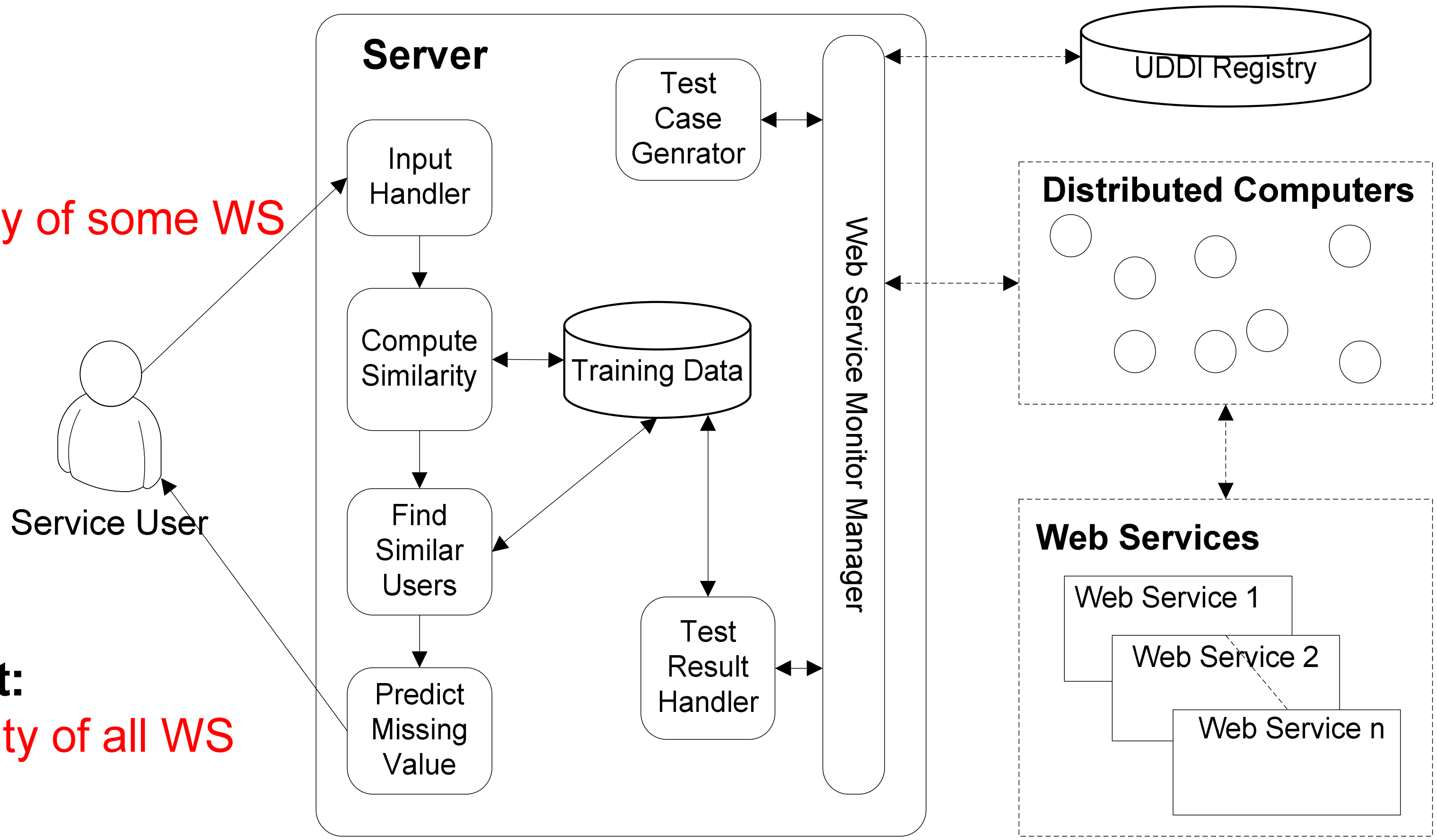


Performance of Selection Results

Part 3: Reliability Prediction of Web Services

System Architecture

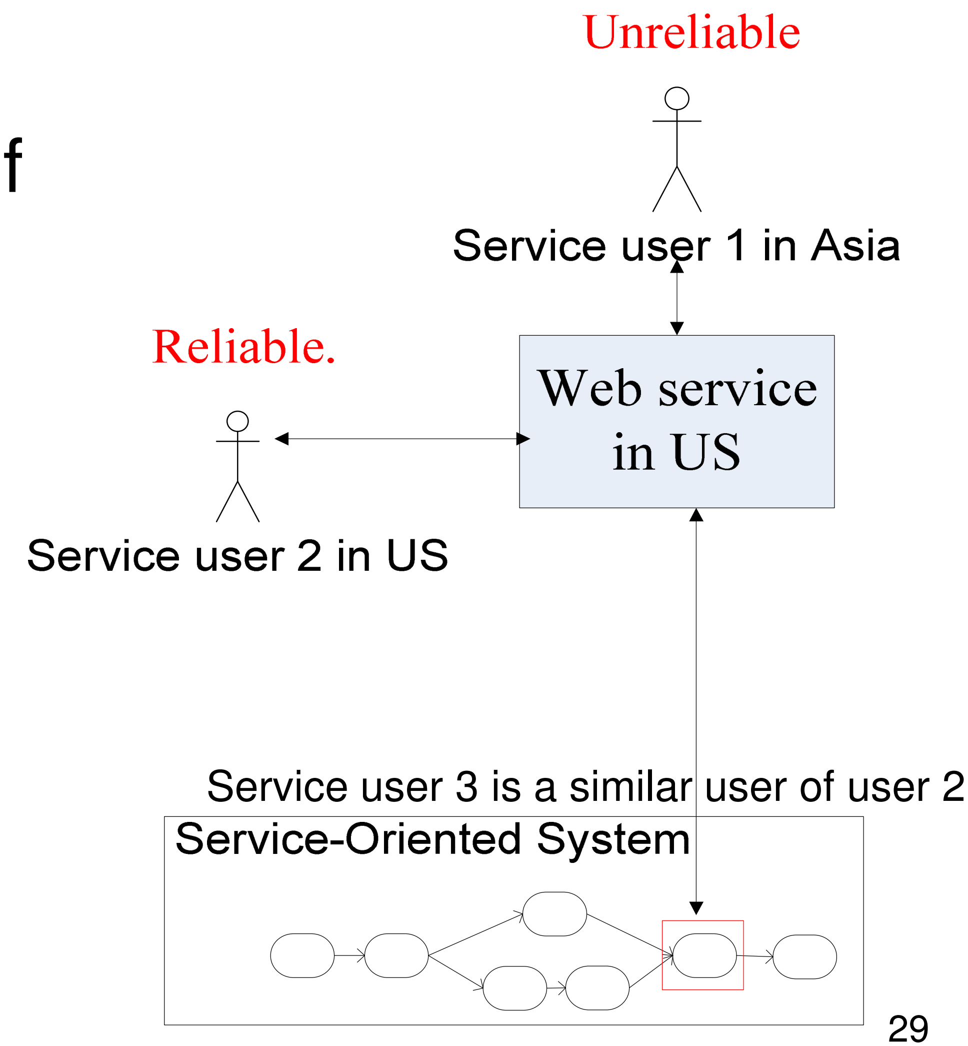
Input:
reliability of some WS



Output:
reliability of all WS

Approach 1: Neighborhood-based

- Key idea: Using past usage experiences of similar users.
- Issue: How to calculate user similarity?



Similarity Computation

- User-item matrix: M×N, each entry is the failure probability of a Web service.

	ws_1	ws_2	ws_3	ws_4	ws_5	ws_6
u_1	0.1	0.1		0.2		0.3
u_2		0.1		0.2	0.5	0.3
u_3	0.4		0.3		0.1	
u_4		0.6		0.4		
u_5	0.5		0.3			0.3

- Pearson Correlation Coefficient (PCC)

$$Sim(a,u) = \frac{\sum_{i \in I_a \cap I_u} (p_{a,i} - \overline{p_a})(p_{u,i} - \overline{p_u})}{\sqrt{\sum_{i \in I_a \cap I_u} (p_{a,i} - \overline{p_a})^2} \sqrt{\sum_{i \in I_a \cap I_u} (p_{u,i} - \overline{p_u})^2}}$$

Similar User Selection

- For a user *u,* a set of similar users *S(u)* can be found by:

$$S(u) = \{a | Sim(u,a) \geq Sim_k, Sim(u,a) > 0, a \neq u\}$$

- Sim_k is the k^{th} largest PCC value with the current user *u*.
- *Sim*(*u, a*) > 0 is to exclude the dissimilar users.
- *Sim*(*u, a*) can be calculated by PCC.

Missing Value Prediction

- Given a missing value $p_{u,i}$, if the user u has similar users (*S(u) ≠null*), the missing value can be predicted by:

$$p_{u,i} = \overline{p_u} + \sum_{a \in S(u)} w_a \times (p_{a,i} - \overline{p_a}),$$

- $\overline{p_u}$ and $\overline{p_a}$ are average failure probabilities of different Web services observed by user *u* and user *a*.
- w_a can be calcualted by:

$$w_a = \frac{Sim(a,u)}{\sum_{b \in S(u)} Sim(b,u)}.$$

Missing Value Prediction

- Similar user + Similar Web services

$$
\begin{aligned}
p_{u,i} = \lambda \times & \underbrace{\boxed{\left(\overline{p_u} + \sum_{a \in S(u)} w_a \times (p_{a,i} - \overline{p_a})\right)}}_{\text{UPCC}} + \\
(1-\lambda) \times & \underbrace{\boxed{\left(\overline{p_i} + \sum_{k \in S(i)} w_k \times (p_{u,k} - \overline{p_k})\right)}}_{\text{IPCC}},
\end{aligned}
$$

$$
p_{u,i} = \begin{cases}
\lambda \times \overline{p_u} + (1-\lambda) \times \overline{p_i}, & \overline{p_u} \neq null \;\&\; \overline{p_i} \neq null \\
\overline{p_u}, & \overline{p_u} \neq null \;\&\; \overline{p_i} = null \\
\overline{p_i}, & \overline{p_u} = null \;\&\; \overline{p_i} \neq null \\
NoPrediction, & \overline{p_u} = null \;\&\; \overline{p_i} = null
\end{cases},
$$

Experiments

- 150 service users and 100 Web services
- 150*100 user-item matrix
- Randomly remove entries
- Predict the removed values
- The removed values are ground truth.

Locations of the Service Users and Web Services

User Locations	Num	WS Locations	Num
United States	72	United States	33
European Union	37	Canada	10
Japan	6	China	8
Canada	5	Germany	7
Germany	4	France	6
Brazil	3	Spain	6
France	3	United Kingdom	5
United Kindom	3	Netherlands	4
Republic of Korea	2	Poland	3
Belgium	1	Republic of Korea	3
Cyprus	1	Switzerland	3
Republic of Czech	1	Italy	2
Finland	1	Australia	1
Greece	1	Belgium	1
Hungary	1	Ireland	1
Ireland	1	Islamic Republic of Iran	1
Norway	1	Japan	1
Poland	1	New Zealand	1
Portugal	1	Norway	1
Puerto Rico	1	Serbia and Montenegro	1
Slovenia	1	South Africa	1
Spain	1	Thailand	1
Taiwan	1		
Uruguay	1		
Total	**150**	**Total**	**100**

Experiments

- Metrics of Prediction Accuracy

$$MAE = \frac{\sum_{u,i} |p_{u,i} - \widehat{p}_{u,i}|}{N}$$

$$RMSE = \sqrt{\frac{\sum_{u,i} (p_{u,i} - \widehat{p}_{u,i})^2}{N}}$$

$p_{u,i}$ *:* the expected value

$\widehat{p}_{u,i}$ *:* the predicted value

N *:* the number of predicted values

Performance Comparison

MAE and RMSE Comparison With Basic Approaches (A smaller MAE or RMSE value means a better performance)

Metric	Density	Methods	Training Users = 100						Training Users = 140					
			Response Time			Failure Rate			Response Time			Failure Rate		
			G10	G20	G30	G10	G20	G30	G10	G20	G30	G10	G20	G30
MAE	10%	UMEAN	1623	1539	1513	5.71%	5.58%	5.53%	1521	1439	1399	5.01%	5.00%	4.97%
		IMEAN	903	901	907	2.40%	2.36%	2.46%	861	872	855	1.62%	1.58%	1.68%
		UPCC	1148	877	810	4.85%	4.20%	3.86%	968	782	684	4.11%	3.47%	3.28%
		IPCC	768	736	736	2.24%	2.16%	2.21%	585	596	605	1.39%	1.33%	1.42%
		WSRec	**758**	**700**	**672**	**2.21%**	**2.08%**	**2.08%**	**560**	**533**	**500**	**1.36%**	**1.26%**	**1.24%**
	20%	UMEAN	1585	1548	1508	5.74%	5.53%	5.51%	1464	1410	1390	5.21%	4.98%	4.95%
		IMEAN	866	859	861	2.36%	2.34%	2.29%	833	837	840	1.56%	1.61%	1.62%
		UPCC	904	722	626	4.40%	3.43%	2.85%	794	626	540	3.93%	2.96%	2.43%
		IPCC	606	610	639	2.01%	1.98%	1.98%	479	509	538	1.17%	1.22%	1.28%
		WSRec	**586**	**551**	**546**	**1.93%**	**1.80%**	**1.70%**	**445**	**428**	**416**	**1.10%**	**1.08%**	**1.07%**
	30%	UMEAN	1603	1543	1508	5.64%	5.58%	5.56%	1494	1430	1387	5.12%	4.98%	4.93%
		IMEAN	856	854	853	2.26%	2.29%	2.30%	823	823	827	1.56%	1.58%	1.58%
		UPCC	915	671	572	4.25%	3.25%	2.58%	803	576	491	3.76%	2.86%	2.06%
		IPCC	563	566	602	1.84%	1.83%	1.86%	439	467	507	1.10%	1.12%	1.17%
		WSRec	**538**	**504**	**499**	**1.78%**	**1.69%**	**1.63%**	**405**	**385**	**378**	**1.05%**	**1.00%**	**0.98%**
RMSE	10%	UMEAN	3339	3250	3192	15.47%	15.04%	14.74%	3190	3109	3069	14.75%	14.42%	13.99%
		IMEAN	1441	1436	1442	5.61%	5.58%	5.85%	1112	1140	1107	3.27%	3.26%	3.38%
		UPCC	2036	1455	1335	10.84%	7.51%	6.55%	1585	1174	1005	8.86%	5.42%	4.96%
		IPCC	1335	1288	1278	5.36%	5.27%	5.53%	850	871	867	2.87%	2.82%	2.96%
		WSRec	**1329**	**1247**	**1197**	**5.31%**	**5.12%**	**5.11%**	**819**	**789**	**734**	**2.80%**	**2.61%**	**2.61%**
	20%	UMEAN	3332	3240	3211	15.49%	15.05%	14.80%	3190	3124	3062	14.72%	14.24%	14.07%
		IMEAN	1269	1252	1257	4.67%	4.62%	4.54%	997	1001	1002	2.53%	2.61%	2.63%
		UPCC	1356	1128	1019	8.07%	5.31%	4.58%	1028	837	730	7.35%	4.20%	3.24%
		IPCC	1020	1016	1056	4.15%	4.13%	4.12%	664	700	731	2.00%	2.09%	2.19%
		WSRec	**997**	**946**	**937**	**4.04%**	**3.83%**	**3.67%**	**620**	**598**	**581**	**1.88%**	**1.84%**	**1.83%**
	30%	UMEAN	3336	3246	3197	15.49%	15.00%	14.68%	3178	3103	3086	14.68%	14.25%	14.07%
		IMEAN	1207	1209	1203	4.21%	4.23%	4.22%	955	954	957	2.28%	2.29%	2.28%
		UPCC	1267	1035	924	7.72%	5.09%	4.15%	988	741	644	6.49%	3.90%	2.66%
		IPCC	950	957	995	3.72%	3.71%	3.75%	611	642	685	1.73%	1.74%	1.81%
		WSRec	**921**	**884**	**869**	**3.64%**	**3.46%**	**3.37%**	**564**	**540**	**528**	**1.64%**	**1.55%**	**1.52%**

Drawbacks of Neighborhood-based Method

- Computational complexity $O(mn+n^2)$
- Matrix sparsity problem
  - Not easy to find similar users

	i_1	i_2	i_3	i_4	i_5	i_6
u_1	0.5					0.4
u_2		0.1				
u_3					0.9	
u_4				0.7		
u_5	0.5					

Approach 2: Model-based Method

- A small number of factors influencing the QoS performance
- A user's Web service QoS experiences correspond to a linear combination of the factors
- Each row of U^T are a set of feature factors, and each column of V is a set of linear predictors

	c_1	c_2	c_3	c_4	c_5	c_6
u_1	0.98	0.23		0.22		
u_2	0.13		0.27		0.25	
u_3		0.37			0.36	
u_4	0.69		0.22	0.22		0.34

(b) User-Component Matrix

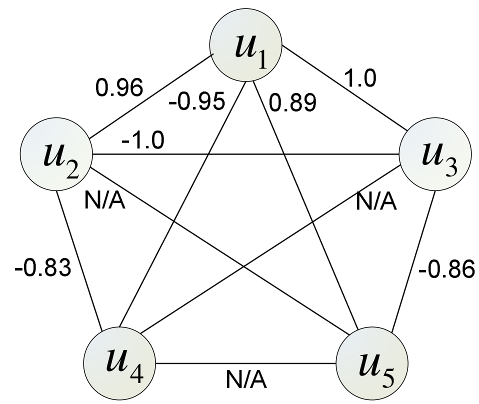
$$\min_{U,V} \mathcal{L}(R,U,V) = \frac{1}{2}\sum_{i=1}^{m}\sum_{j=1}^{n} I_{ij}^{R}(R_{ij} - U_i^T V_j)^2 + \frac{\lambda_U}{2}\|U\|_F^2 + \frac{\lambda_V}{2}\|V\|_F^2,$$

$$\begin{bmatrix} 0.32 & 0.15 & 0.31 & 0.33 \\ 0.23 & 0.15 & 0.26 & 0.28 \\ 0.30 & 0.20 & 0.24 & 0.34 \\ 0.47 & 0.23 & 0.59 & 0.21 \end{bmatrix} \times \begin{bmatrix} 0.73 & 0.35 & 0.31 & 0.26 & 0.32 & 0.42 \\ 0.60 & 0.31 & 0.27 & 0.22 & 0.28 & 0.36 \\ 0.69 & 0.37 & 0.32 & 0.27 & 0.33 & 0.45 \\ 0.95 & 0.46 & 0.42 & 0.35 & 0.41 & 0.54 \end{bmatrix}$$

NIMF: Neighborhood–Integrated Matrix Factorization

	i_1	i_2	i_3	i_4	i_5	i_6
u_1	0.5	1.2		0.3		0.4
u_2		0.8		0.6	0.5	
u_3	0.4		0.3		0.9	
u_4		0.6		0.7		
u_5	0.5		0.7			0.3

(a) User-Item Matrix



(b) PCC Values

$$
\mathcal{L}(R,S,U,V)
$$
$$
= \frac{1}{2}\sum_{i=1}^{m}\sum_{j=1}^{n} I_{ij}^{R}\Big(R_{ij} - \big(\alpha U_i^T V_j + (1-\alpha)\sum_{k\in\mathcal{T}(i)} S_{ik} U_k^T V_j\big)\Big)^2
$$
$$
+ \frac{\lambda_U}{2}\|U\|_F^2 + \frac{\lambda_V}{2}\|V\|_F^2,
$$

$$
S_{ik} = \frac{PCC(i,k)}{\sum_{k\in\mathcal{T}(i)} PCC(i,k)}
$$

Location Information

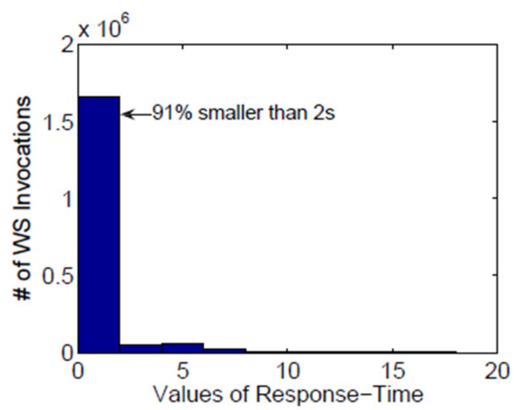
(a) Locations of Service Users

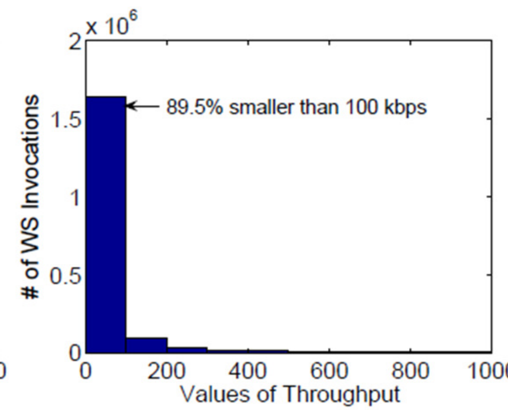
(b) Locations of Web Services

Location Information: (a) locations of service users, totally 339 service users from 30 countries are plotted; (b) locations of Web services, totally 5,825 real-world Web services from 73 countries are plotted. Each user in (a) invoked all the Web services in (b). Totally 1,974,675 Web service invocation results are collected in our experiments.

Statistics of the WS QoS Dataset

Statistics	Values
Num. of Service Users	339
Num. of Web Services	5,825
Num. of Web Service Invocations	1,974,675
Range of Response-time	1-20 s
Avg. Value of Response-time	0.9085 s
Range of Throughput	1-1000 kbps
Avg. Value of Throughput	47.5616 kbps



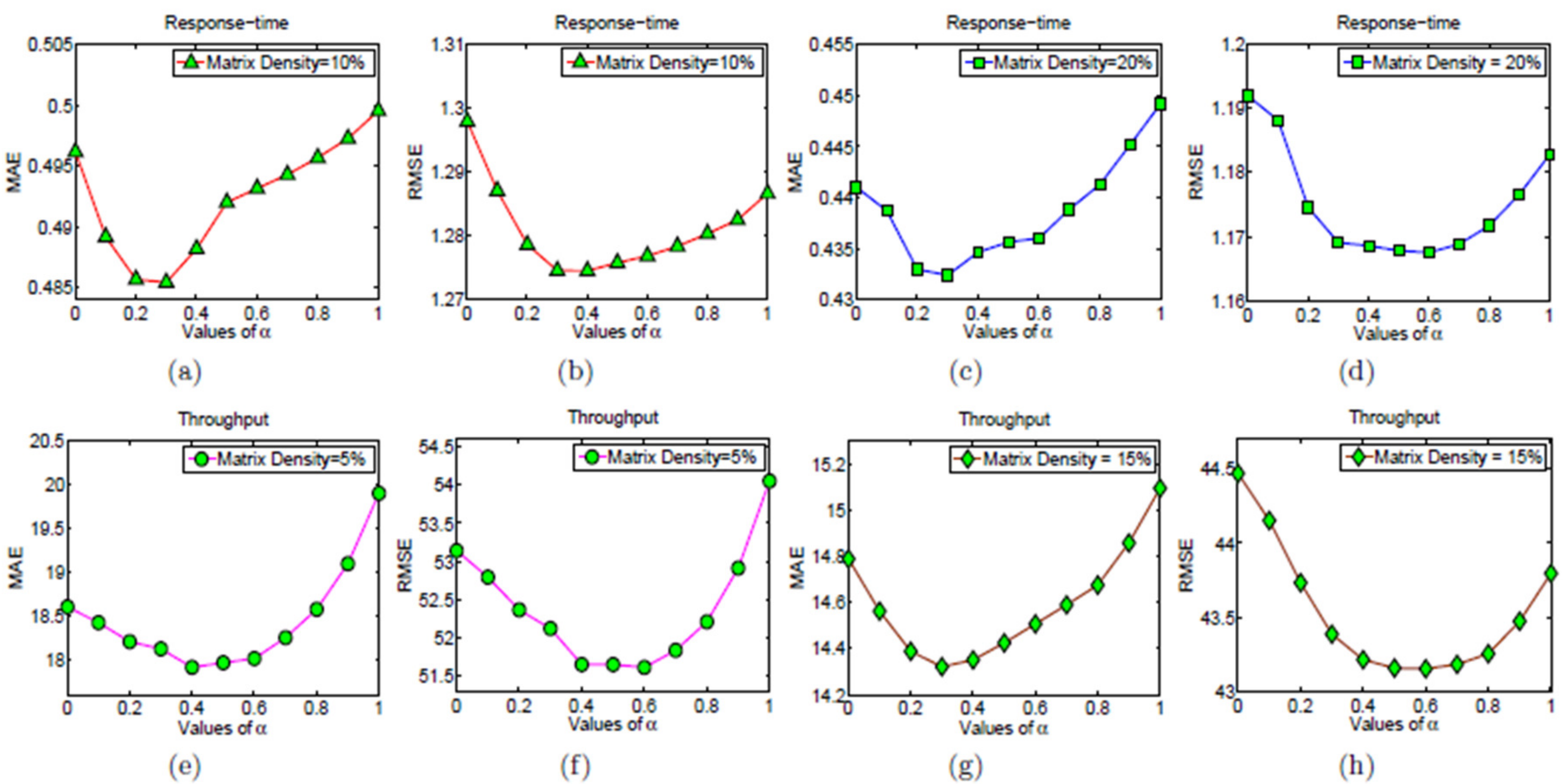


Performance Comparison

Performance Comparison (A Smaller MAE or RMSE Value Means a Better Performance)

QoS	Methods	Matrix Density=5%		Matrix Density=10%		Matrix Density=15%		Matrix Density=20%	
		MAE	RMSE	MAE	RMSE	MAE	RMSE	MAE	RMSE
Response-time (0-20 s)	UMEAN	0.8785	1.8591	0.8783	1.8555	0.8768	1.8548	0.8747	1.8557
	IMEAN	0.7015	1.5813	0.6918	1.5440	0.6867	1.5342	0.6818	1.5311
	UPCC	0.6261	1.4078	0.5517	1.3151	0.5159	1.2680	0.4884	1.2334
	IPCC	0.6897	1.4296	0.5917	1.3268	0.5037	1.2552	0.4459	1.2095
	WSRec	0.6234	1.4078	0.5365	1.3043	0.4965	1.2467	0.4407	1.2012
	NMF	0.6182	1.5746	0.6040	1.5494	0.5990	1.5345	0.5982	1.5331
	PMF	0.5678	1.4735	0.4996	1.2866	0.4720	1.2163	0.4492	1.1828
	NIMF	**0.5514**	**1.4075**	**0.4854**	**1.2745**	**0.4534**	**1.1980**	**0.4357**	**1.1678**
Throughput (0-1000 kbps)	UMEAN	54.0084	110.2821	53.6700	110.2977	53.8792	110.1751	53.7114	110.1708
	IMEAN	27.3558	66.6344	26.8318	64.7674	26.6239	64.3986	26.6364	64.1082
	UPCC	26.1230	61.6108	21.2695	54.3701	18.7455	50.7768	17.5546	48.2621
	IPCC	29.2651	64.2285	27.3993	60.0825	26.4319	57.8593	25.0273	55.4970
	WSRec	25.8755	60.8685	19.9754	54.8761	17.5543	47.8235	16.0762	47.8749
	NMF	25.7529	65.8517	17.8411	53.9896	15.8939	51.7322	15.2516	48.6330
	PMF	19.9034	54.0508	16.1755	46.4439	15.0956	43.7957	14.6694	42.4855
	NIMF	**17.9297**	**51.6573**	**16.0542**	**45.9409**	**14.4363**	**43.1596**	**13.7099**	**41.1689**

Impact of Parameter



Impact of Parameter α (Dimensionality = 10)

The parameter α controls how much our method relies on the users themselves and their similar users

Conclusion

- Performance evaluation of Web services
  - A user-collaborative framework
  - Two large scale research datasets
- Fault-tolerant Web services
  - Adaptive fault tolerance strategy design
  - Systematic fault-tolerant framework
- Reliability prediction of Web services
  - Neighborhood-based approach
  - Model-based approach

- Service reliability engineering is a challenging and important research topic.

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Service Reliability Engineering: Performance Evaluation, Fault Tolerance, and Reliability Prediction

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Thank You!

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