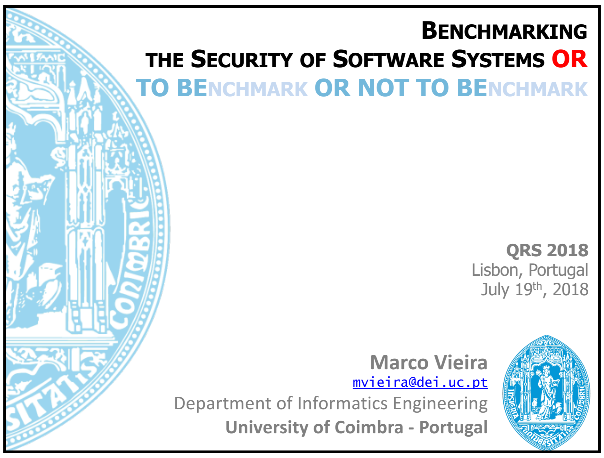
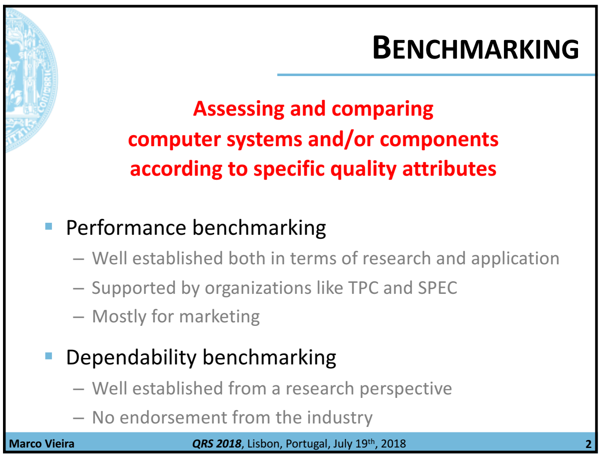


BENCHMARKING THE SECURITY OF SOFTWARE SYSTEMS OR TO BENCHMARK OR NOT TO BENCHMARK

QRS 2018
Lisbon, Portugal
July 19th, 2018

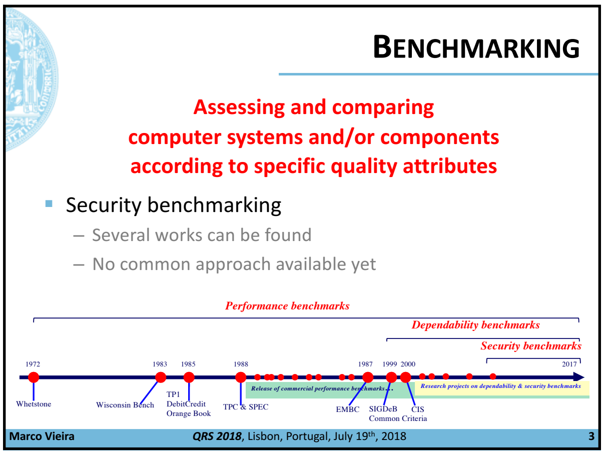
Marco Vieira
mvieira@dei.uc.pt
Department of Informatics Engineering
University of Coimbra - Portugal



BENCHMARKING

Assessing and comparing computer systems and/or components according to specific quality attributes

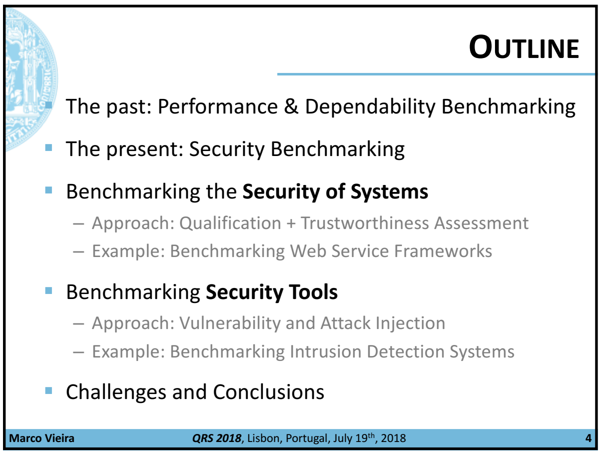
- Performance benchmarking
  - Well established both in terms of research and application
  - Supported by organizations like TPC and SPEC
  - Mostly for marketing
- Dependability benchmarking
  - Well established from a research perspective
  - No endorsement from the industry



BENCHMARKING

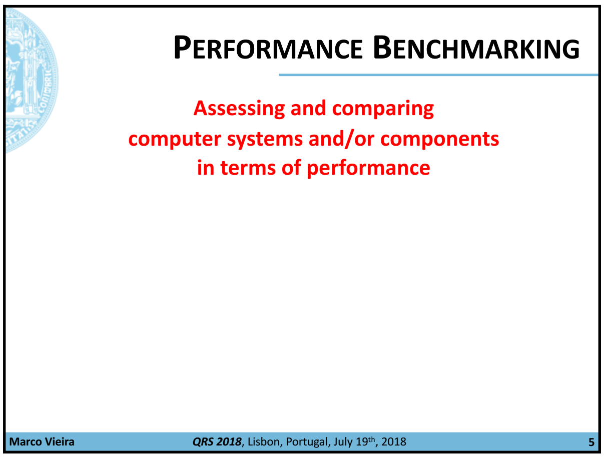
Assessing and comparing computer systems and/or components according to specific quality attributes

- Security benchmarking
  - Several works can be found
  - No common approach available yet



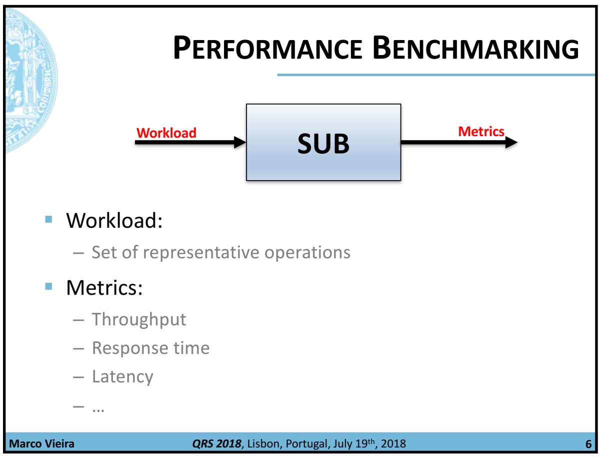
OUTLINE

- The past: Performance & Dependability Benchmarking
- The present: Security Benchmarking
- Benchmarking the **Security of Systems**
  - Approach: Qualification + Trustworthiness Assessment
  - Example: Benchmarking Web Service Frameworks
- Benchmarking **Security Tools**
  - Approach: Vulnerability and Attack Injection
  - Example: Benchmarking Intrusion Detection Systems
- Challenges and Conclusions



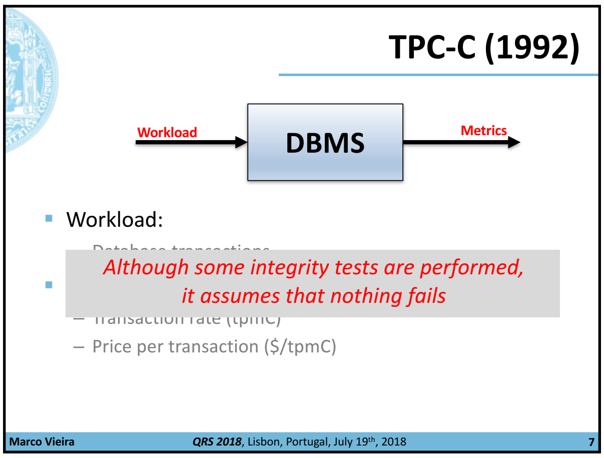
PERFORMANCE BENCHMARKING

Assessing and comparing computer systems and/or components in terms of performance



PERFORMANCE BENCHMARKING

- Workload:
  - Set of representative operations
- Metrics:
  - Throughput
  - Response time
  - Latency
  - …

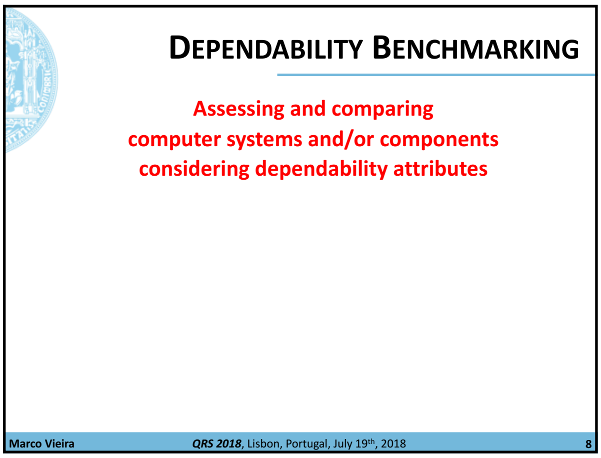


TPC-C (1992)

Workload
DBMS
Metrics

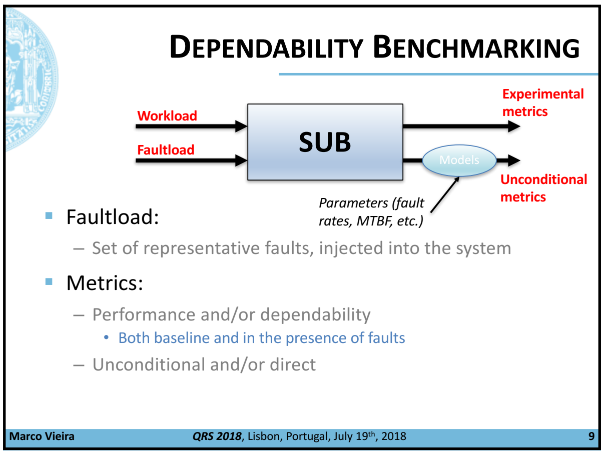
- Workload:
  - Database transactions
-
  - Transaction rate (tpmC)
  - Price per transaction ($/tpmC)

*Although some integrity tests are performed,
it assumes that nothing fails*



Dependability Benchmarking

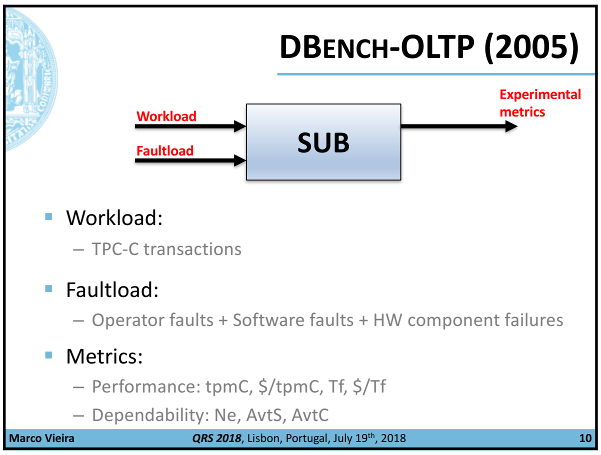
**Assessing and comparing
computer systems and/or components
considering dependability attributes**



Dependability Benchmarking

Workload
Faultload
SUB
Experimental metrics
Models
Unconditional metrics
Parameters (fault rates, MTBF, etc.)

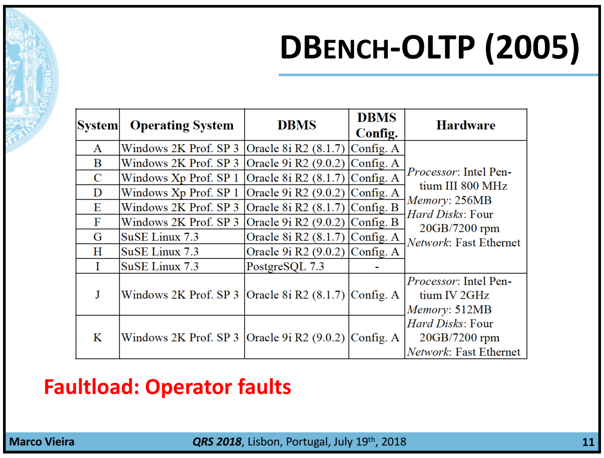
- Faultload:
  - Set of representative faults, injected into the system
- Metrics:
  - Performance and/or dependability
    - Both baseline and in the presence of faults
  - Unconditional and/or direct



DBench-OLTP (2005)

Workload
Faultload
SUB
Experimental metrics

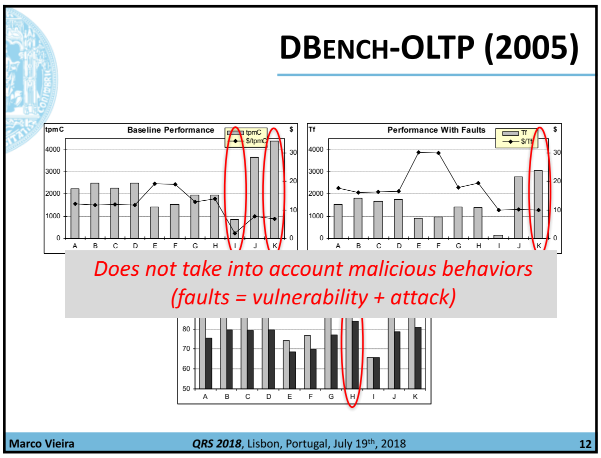
- Workload:
  - TPC-C transactions
- Faultload:
  - Operator faults + Software faults + HW component failures
- Metrics:
  - Performance: tpmC, $/tpmC, Tf, $/Tf
  - Dependability: Ne, AvtS, AvtC



DBench-OLTP (2005)

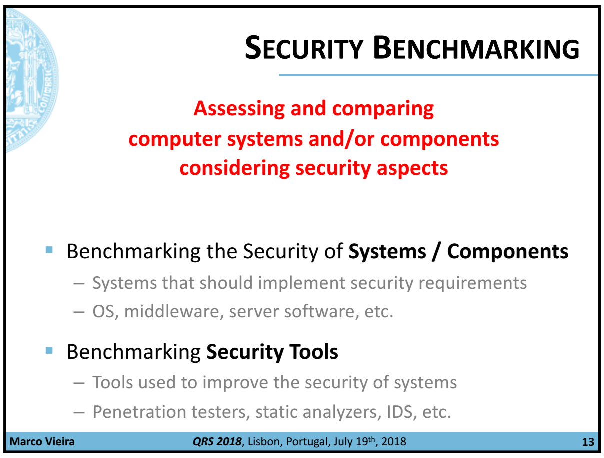
System	Operating System	DBMS	DBMS Config.	Hardware
A	Windows 2K Prof. SP 3	Oracle 8i R2 (8.1.7)	Config. A	*Processor*: Intel Pentium III 800 MHz *Memory*: 256MB *Hard Disks*: Four 20GB/7200 rpm *Network*: Fast Ethernet
B	Windows 2K Prof. SP 3	Oracle 9i R2 (9.0.2)	Config. A	
C	Windows Xp Prof. SP 1	Oracle 8i R2 (8.1.7)	Config. A	
D	Windows Xp Prof. SP 1	Oracle 9i R2 (9.0.2)	Config. A	
E	Windows 2K Prof. SP 3	Oracle 8i R2 (8.1.7)	Config. B	
F	Windows 2K Prof. SP 3	Oracle 9i R2 (9.0.2)	Config. B	
G	SuSE Linux 7.3	Oracle 8i R2 (8.1.7)	Config. A	
H	SuSE Linux 7.3	Oracle 9i R2 (9.0.2)	Config. A	
I	SuSE Linux 7.3	PostgreSQL 7.3	-	
J	Windows 2K Prof. SP 3	Oracle 8i R2 (8.1.7)	Config. A	*Processor*: Intel Pentium IV 2GHz *Memory*: 512MB *Hard Disks*: Four 20GB/7200 rpm *Network*: Fast Ethernet
K	Windows 2K Prof. SP 3	Oracle 9i R2 (9.0.2)	Config. A	

Faultload: Operator faults



DBench-OLTP (2005)

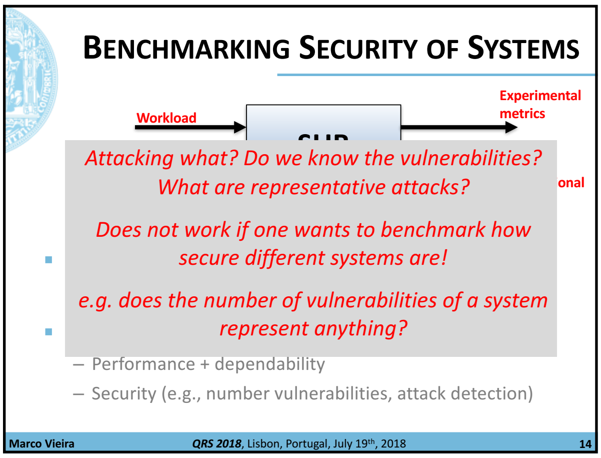
*Does not take into account malicious behaviors
(faults = vulnerability + attack)*



Security Benchmarking

Assessing and comparing computer systems and/or components considering security aspects

- Benchmarking the Security of **Systems / Components**
  - Systems that should implement security requirements
  - OS, middleware, server software, etc.
- Benchmarking **Security Tools**
  - Tools used to improve the security of systems
  - Penetration testers, static analyzers, IDS, etc.



Benchmarking Security of Systems

Workload

Experimental metrics

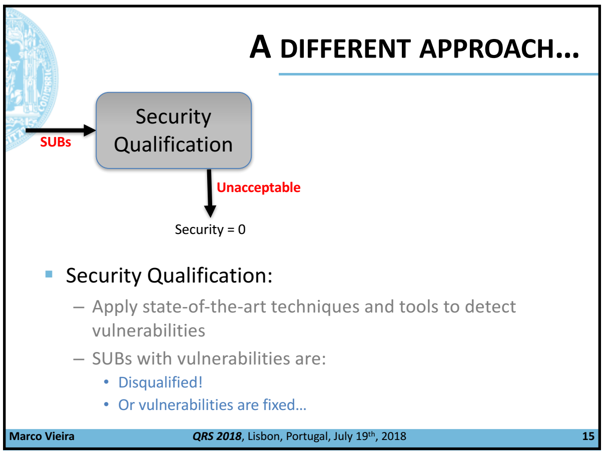
onal

Attacking what? Do we know the vulnerabilities?
What are representative attacks?

Does not work if one wants to benchmark how secure different systems are!

e.g. does the number of vulnerabilities of a system represent anything?

- Performance + dependability
- Security (e.g., number vulnerabilities, attack detection)

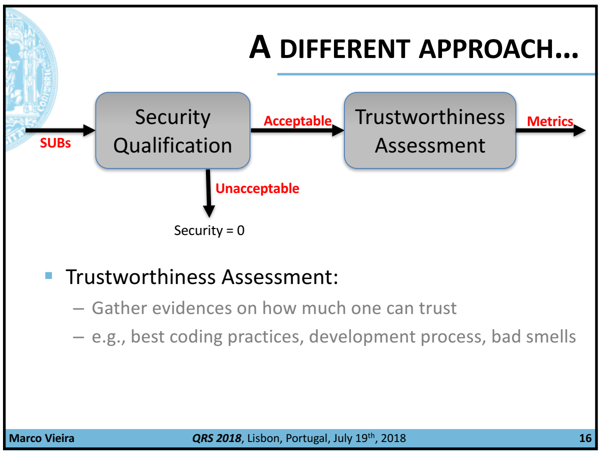


A Different Approach…

SUBs → Security Qualification

Unacceptable → Security = 0

- Security Qualification:
  - Apply state-of-the-art techniques and tools to detect vulnerabilities
  - SUBs with vulnerabilities are:
    - Disqualified!
    - Or vulnerabilities are fixed…

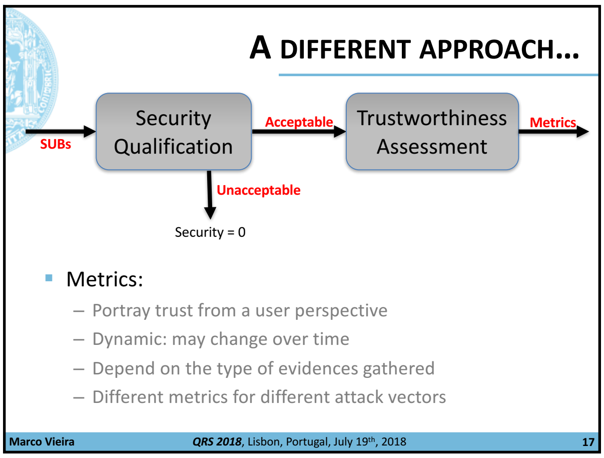


A Different Approach…

SUBs → Security Qualification → Acceptable → Trustworthiness Assessment → Metrics

Unacceptable → Security = 0

- Trustworthiness Assessment:
  - Gather evidences on how much one can trust
  - e.g., best coding practices, development process, bad smells

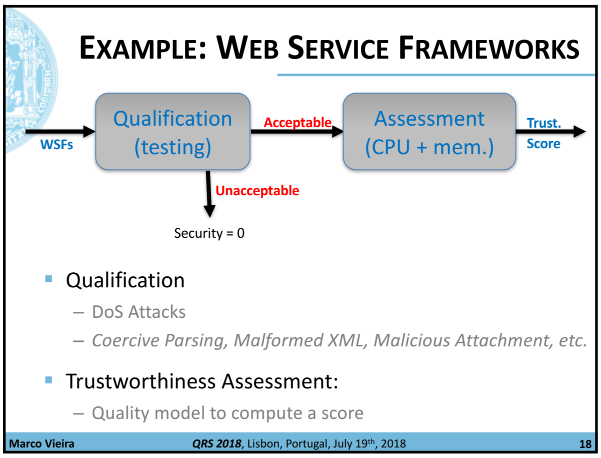


A Different Approach…

SUBs → Security Qualification → Acceptable → Trustworthiness Assessment → Metrics

Unacceptable → Security = 0

- Metrics:
  - Portray trust from a user perspective
  - Dynamic: may change over time
  - Depend on the type of evidences gathered
  - Different metrics for different attack vectors

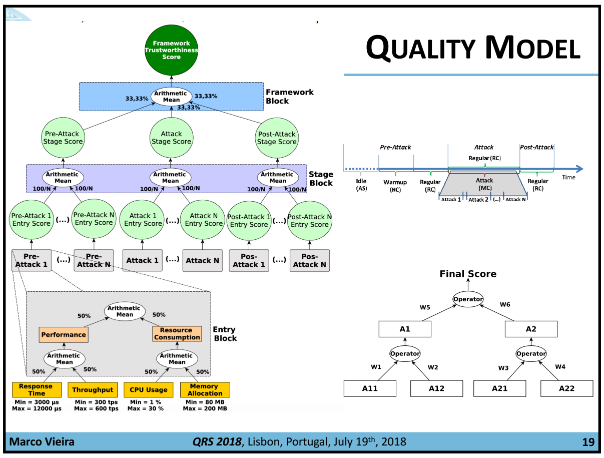


Example: Web Service Frameworks

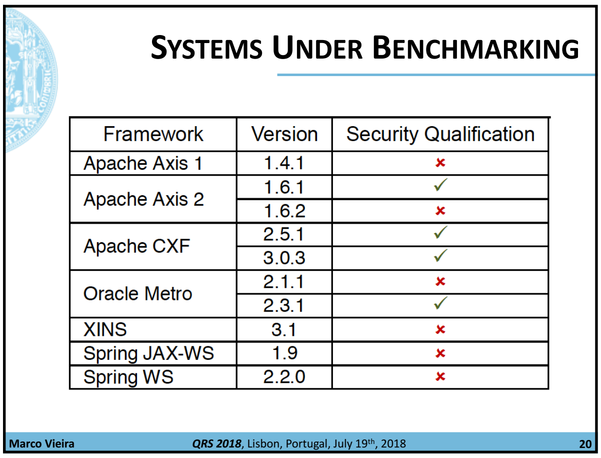
WSFs → Qualification (testing) → Acceptable → Assessment (CPU + mem.) → Trust. Score

Unacceptable → Security = 0

- Qualification
  - DoS Attacks
  - *Coercive Parsing, Malformed XML, Malicious Attachment, etc.*
- Trustworthiness Assessment:
  - Quality model to compute a score

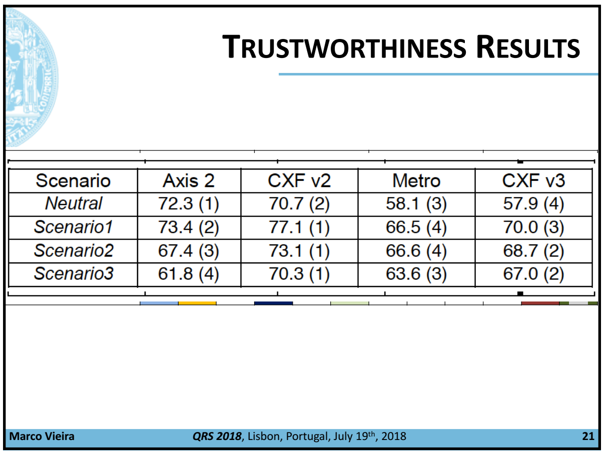


Quality Model



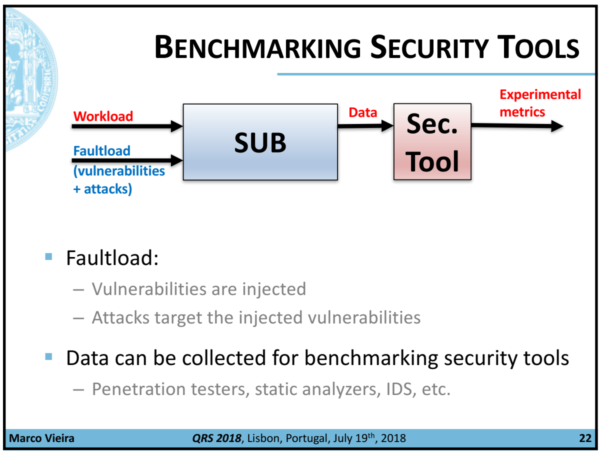
Systems Under Benchmarking

Framework	Version	Security Qualification
Apache Axis 1	1.4.1	✗
Apache Axis 2	1.6.1	✓
	1.6.2	✗
Apache CXF	2.5.1	✓
	3.0.3	✓
Oracle Metro	2.1.1	✗
	2.3.1	✓
XINS	3.1	✗
Spring JAX-WS	1.9	✗
Spring WS	2.2.0	✗



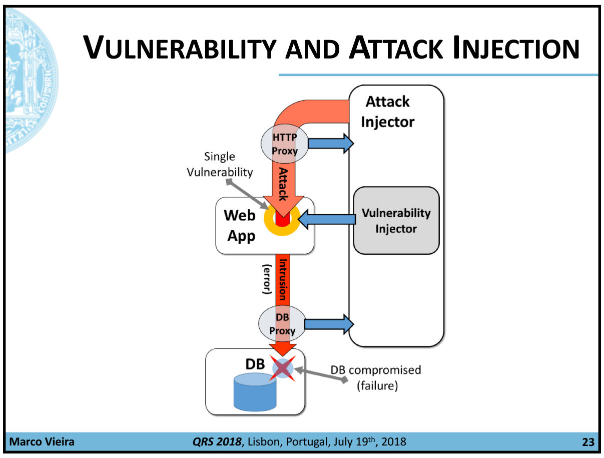
Trustworthiness Results

Scenario	Axis 2	CXF v2	Metro	CXF v3
Neutral	72.3 (1)	70.7 (2)	58.1 (3)	57.9 (4)
Scenario1	73.4 (2)	77.1 (1)	66.5 (4)	70.0 (3)
Scenario2	67.4 (3)	73.1 (1)	66.6 (4)	68.7 (2)
Scenario3	61.8 (4)	70.3 (1)	63.6 (3)	67.0 (2)

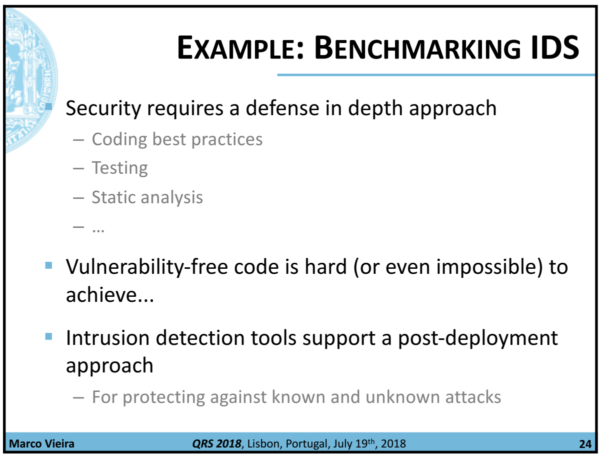


Benchmarking Security Tools

- Faultload:
  - Vulnerabilities are injected
  - Attacks target the injected vulnerabilities
- Data can be collected for benchmarking security tools
  - Penetration testers, static analyzers, IDS, etc.

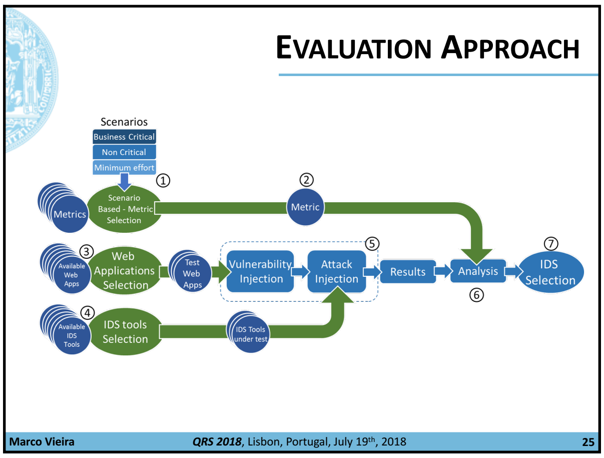


Vulnerability and Attack Injection

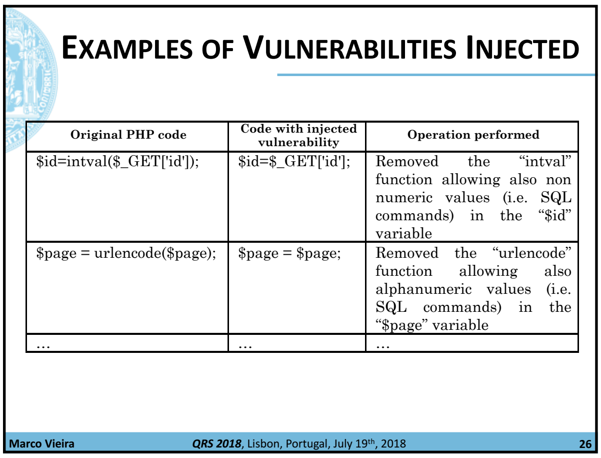


Example: Benchmarking IDS

- Security requires a defense in depth approach
  - Coding best practices
  - Testing
  - Static analysis
  - …
- Vulnerability-free code is hard (or even impossible) to achieve…
- Intrusion detection tools support a post-deployment approach
  - For protecting against known and unknown attacks

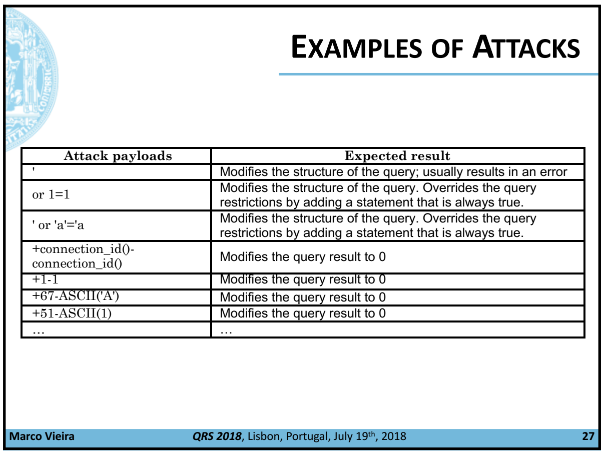


Evaluation Approach



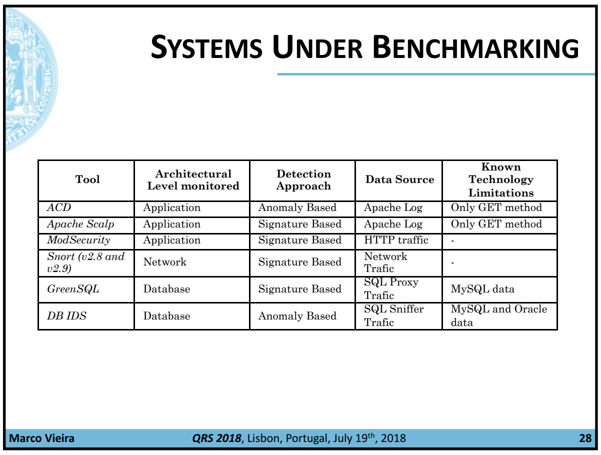
Examples of Vulnerabilities Injected

Original PHP code	Code with injected vulnerability	Operation performed
$id=intval($_GET['id']);	$id=$_GET['id'];	Removed the "intval" function allowing also non numeric values (i.e. SQL commands) in the "$id" variable
$page = urlencode($page);	$page = $page;	Removed the "urlencode" function allowing also alphanumeric values (i.e. SQL commands) in the "$page" variable
…	…	…



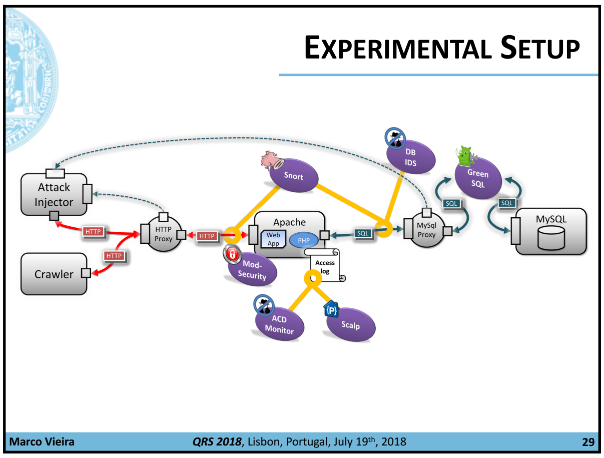
Examples of Attacks

Attack payloads	Expected result
'	Modifies the structure of the query; usually results in an error
or 1=1	Modifies the structure of the query. Overrides the query restrictions by adding a statement that is always true.
' or 'a'='a	Modifies the structure of the query. Overrides the query restrictions by adding a statement that is always true.
+connection_id()-connection_id()	Modifies the query result to 0
+1-1	Modifies the query result to 0
+67-ASCII('A')	Modifies the query result to 0
+51-ASCII(1)	Modifies the query result to 0
…	…

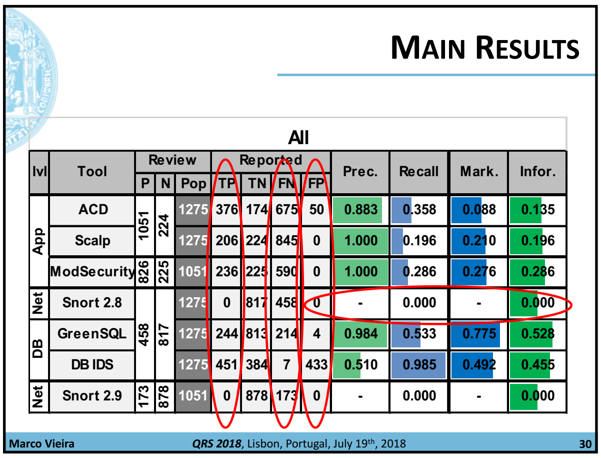


Systems Under Benchmarking

Tool	Architectural Level monitored	Detection Approach	Data Source	Known Technology Limitations
ACD	Application	Anomaly Based	Apache Log	Only GET method
Apache Scalp	Application	Signature Based	Apache Log	Only GET method
ModSecurity	Application	Signature Based	HTTP traffic	-
Snort (v2.8 and v2.9)	Network	Signature Based	Network Trafic	-
GreenSQL	Database	Signature Based	SQL Proxy Trafic	MySQL data
DB IDS	Database	Anomaly Based	SQL Sniffer Trafic	MySQL and Oracle data



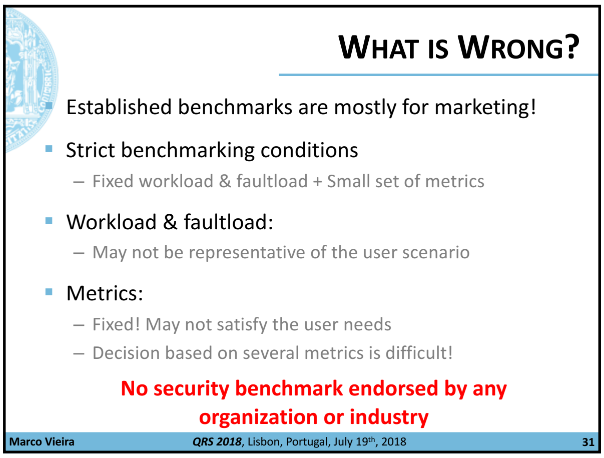
Experimental Setup



Main Results

All

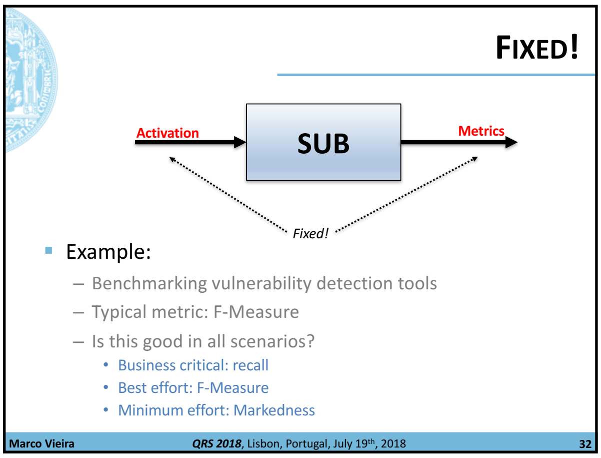
lvl	Tool	Review			Reported				Prec.	Recall	Mark.	Infor.
		P	N	Pop	TP	TN	FN	FP				
App	ACD	1051	224	1275	376	174	675	50	0.883	0.358	0.088	0.135
	Scalp			1275	206	224	845	0	1.000	0.196	0.210	0.196
	ModSecurity	826	225	1051	236	225	590	0	1.000	0.286	0.276	0.286
Net	Snort 2.8	458	817	1275	0	817	458	0	-	0.000	-	0.000
DB	GreenSQL			1275	244	813	214	4	0.984	0.533	0.775	0.528
	DB IDS			1275	451	384	7	433	0.510	0.985	0.492	0.455
Net	Snort 2.9	173	878	1051	0	878	173	0	-	0.000	-	0.000



What is Wrong?

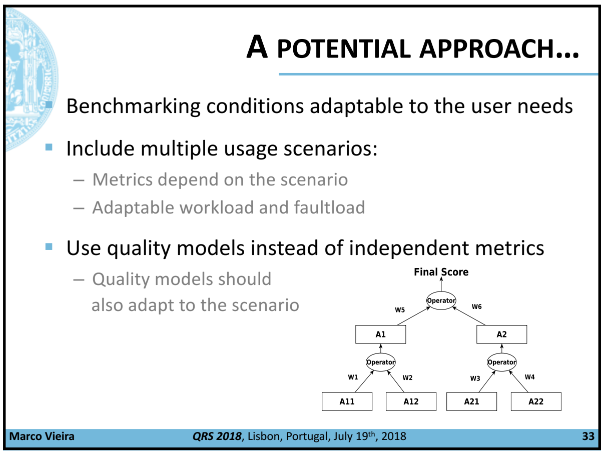
- Established benchmarks are mostly for marketing!
- Strict benchmarking conditions
  - Fixed workload & faultload + Small set of metrics
- Workload & faultload:
  - May not be representative of the user scenario
- Metrics:
  - Fixed! May not satisfy the user needs
  - Decision based on several metrics is difficult!

No security benchmark endorsed by any organization or industry



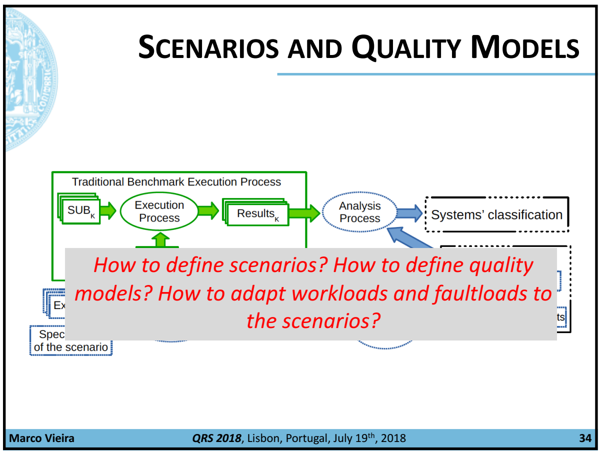
Fixed!

- Example:
  - Benchmarking vulnerability detection tools
  - Typical metric: F-Measure
  - Is this good in all scenarios?
    - Business critical: recall
    - Best effort: F-Measure
    - Minimum effort: Markedness



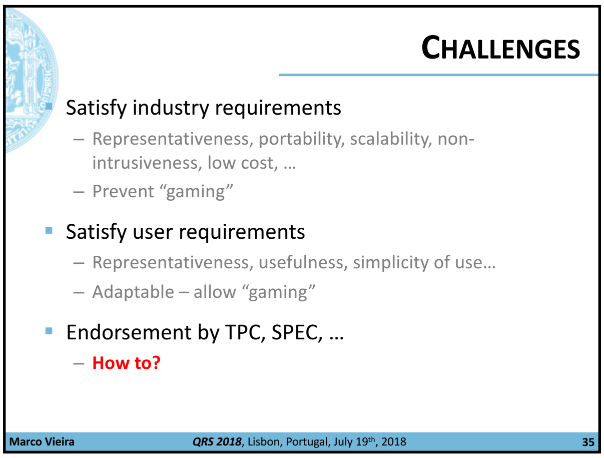
A potential approach…

- Benchmarking conditions adaptable to the user needs
- Include multiple usage scenarios:
  - Metrics depend on the scenario
  - Adaptable workload and faultload
- Use quality models instead of independent metrics
  - Quality models should also adapt to the scenario



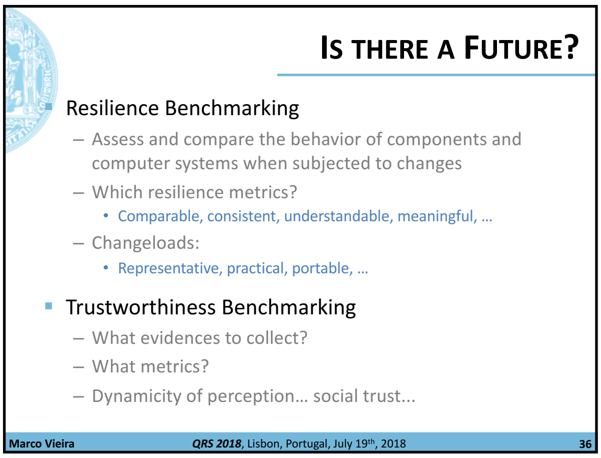
Scenarios and Quality Models

How to define scenarios? How to define quality models? How to adapt workloads and faultloads to the scenarios?



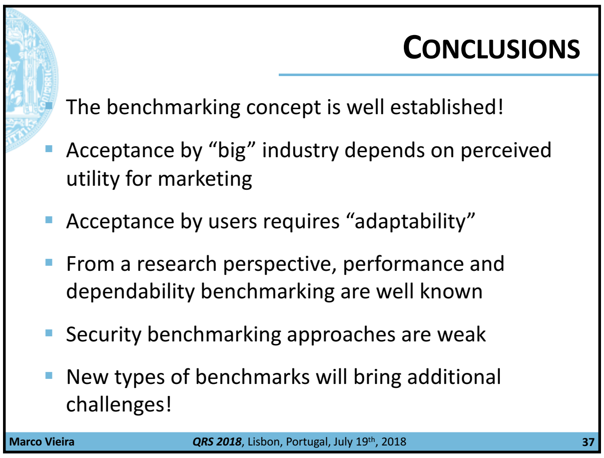
Challenges

- Satisfy industry requirements
  - Representativeness, portability, scalability, non-intrusiveness, low cost, …
  - Prevent "gaming"
- Satisfy user requirements
  - Representativeness, usefulness, simplicity of use…
  - Adaptable – allow "gaming"
- Endorsement by TPC, SPEC, …
  - **How to?**



Is there a Future?

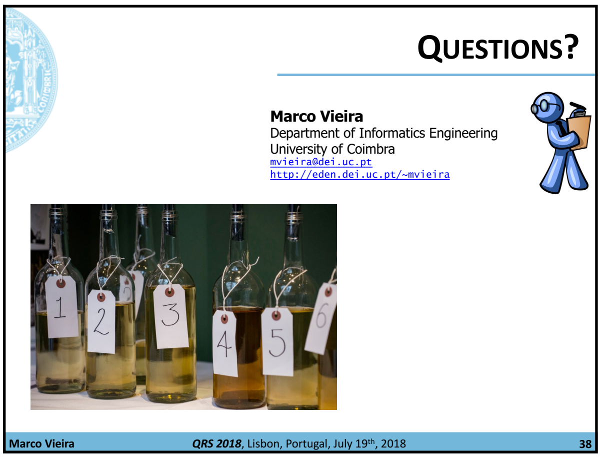
- Resilience Benchmarking
  - Assess and compare the behavior of components and computer systems when subjected to changes
  - Which resilience metrics?
    - Comparable, consistent, understandable, meaningful, …
  - Changeloads:
    - Representative, practical, portable, …
- Trustworthiness Benchmarking
  - What evidences to collect?
  - What metrics?
  - Dynamicity of perception… social trust…



Conclusions

- The benchmarking concept is well established!
- Acceptance by "big" industry depends on perceived utility for marketing
- Acceptance by users requires "adaptability"
- From a research perspective, performance and dependability benchmarking are well known
- Security benchmarking approaches are weak
- New types of benchmarks will bring additional challenges!

Marco Vieira *QRS 2018*, Lisbon, Portugal, July 19th, 2018 37



Questions?

Marco Vieira
Department of Informatics Engineering
University of Coimbra
mvieira@dei.uc.pt
http://eden.dei.uc.pt/~mvieira

Marco Vieira *QRS 2018*, Lisbon, Portugal, July 19th, 2018 38