Vulnerability Discovery Models: Which works, which doesn't?

Università degli Studi di Trento

Viet Hung Nguyen and Fabio Massacci

University of Trento, Italy

{vhnguyen, massacci}@disi.unitn.it

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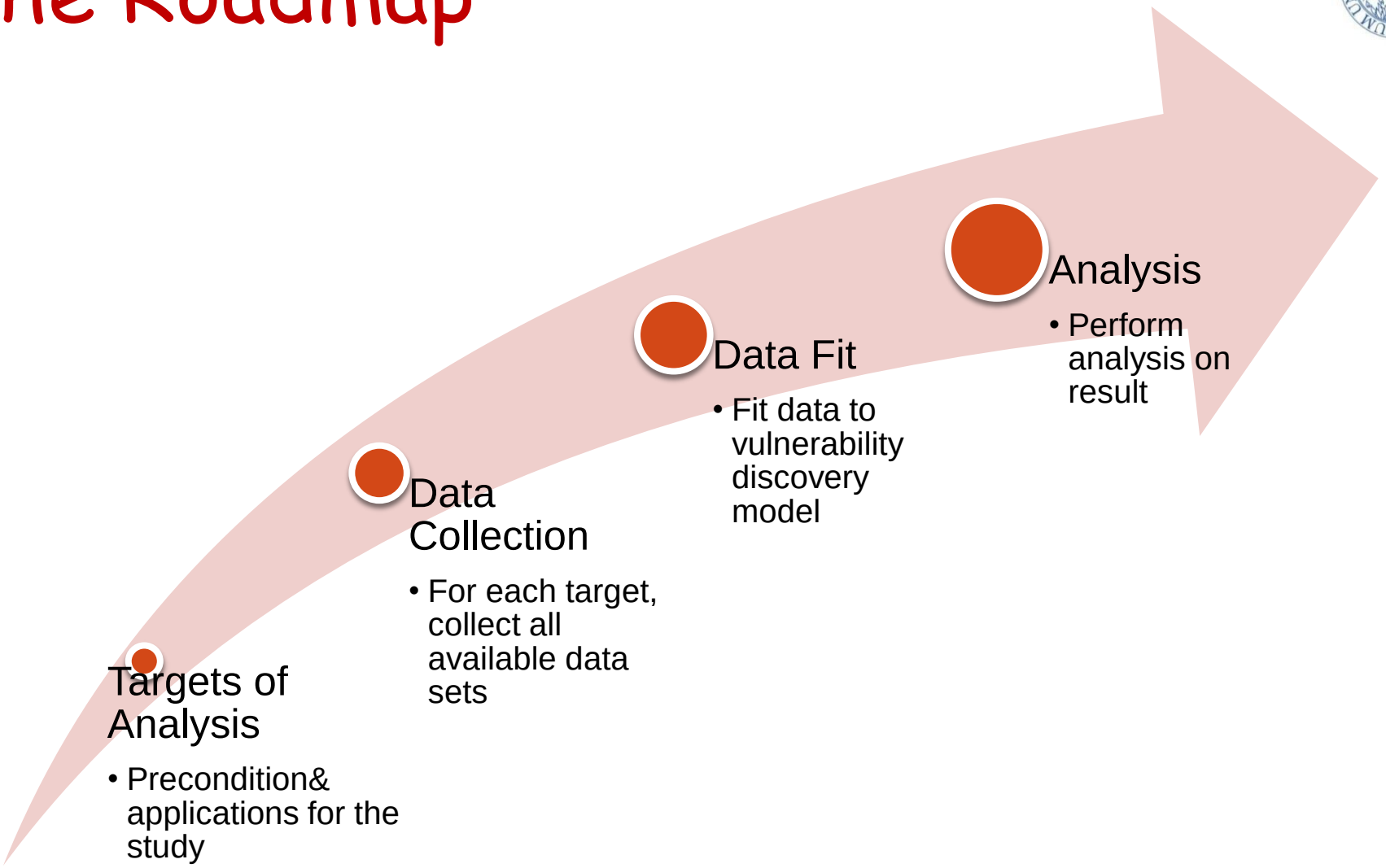
The Roadmap


Targets of Analysis
• Precondition& applications for the study
Data Collection
• For each target, collect all available data sets
Data Fit
• Fit data to vulnerability discovery model
Analysis
• Perform analysis on result

Basic Concepts

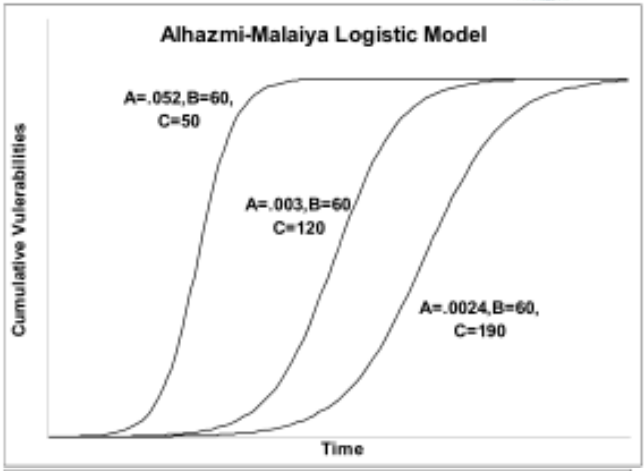
* Vulnerability
  - ✓ An instance of human mistake in specification, development, or configuration of software that its execution can violate the security policy [Krsul98]

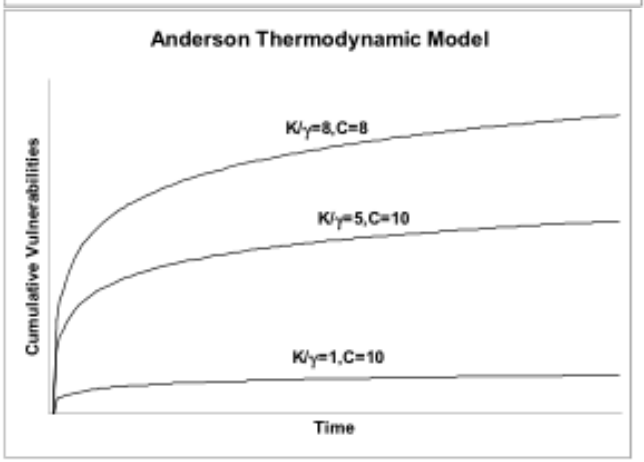
* Vulnerability Discovery Model (VDM)
  - ✓ A post-release stage where people identify and report security flaws of a released software
  - ✓ Usually represented as mathematic curves

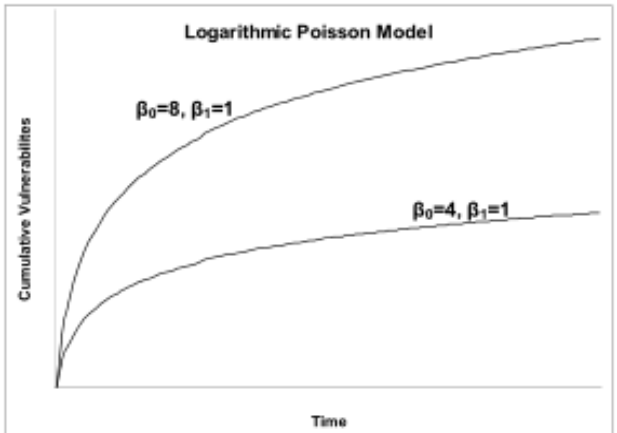
[Krsul98] Krsul I.V, Software Vulnerability Analysis, PhD Thesis, Perdue University, 1998

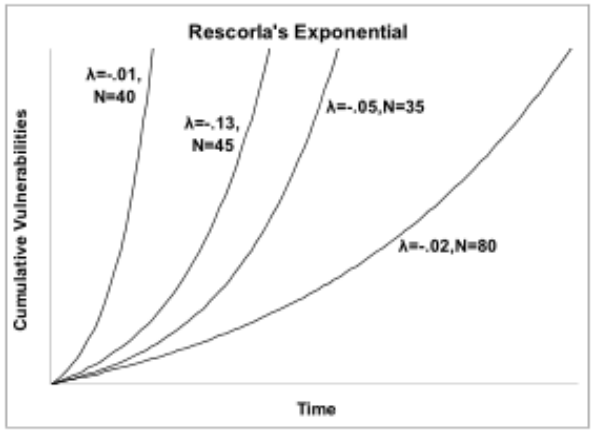
Existing VDMs

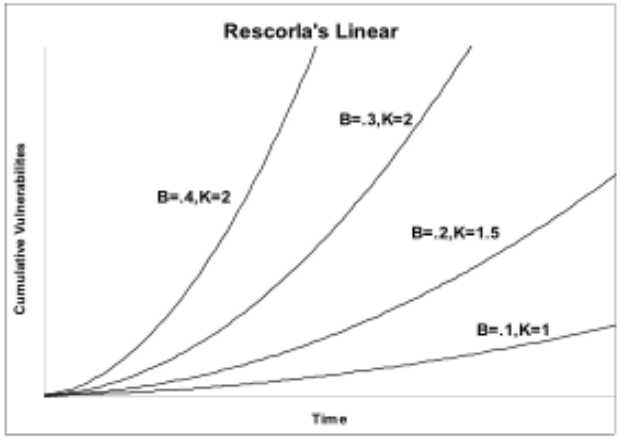
* Alhazmi-Malaiya Logistic (AML)
* Anderson Thermodynamic (AT)
* Linear (LN)
* Logarithmic Poisson (LP)
* Rescolar's Exponential (RE)
* Rescolar's Quadratic/Linear (RQ)







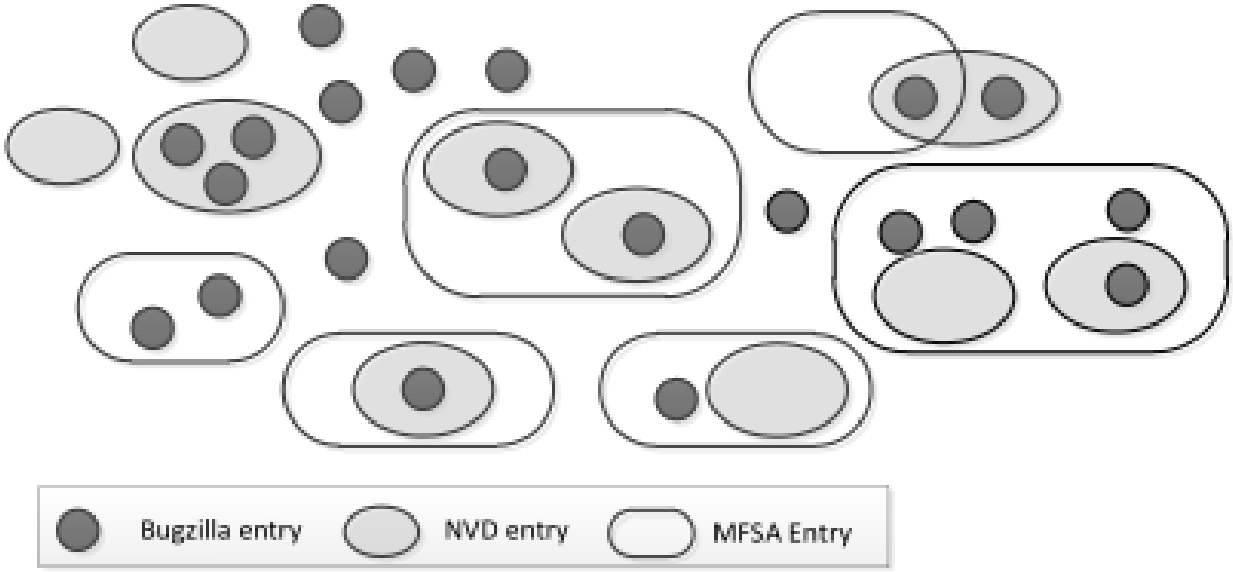




The Fallacy of Measurement

- How to measure vulnerabilities?
  - ✓ Different definitions/sources of vulnerabilities
  - ✓ Eg. Firefox:
    - Mozilla Bugzilla (only security-relevant bugs)
    - Mozilla Foundation Security Advisory (MFSA)
    - National Vulnerability Database (NVD)
  - ✓ What is the number of vulns?
    - 6 MFSA, 10 NVD, 14 (security) Bugzilla.

Vulnerability space of Firefox



Research Questions

- RQ1: which VDM works, which doesn't?
  - ✓ Do the existing VDMs work?
  - ✓ Which VDM is the best one?

- RQ2: How do different ways of counting vulns impact to the performance of VDMs?
  - ✓ Do VDMs behave differently with different types of data set?

Types of Vulnerability Data Set

* Release X (eg. FF3.0)
  - ✓ NVD(X) : 1 vuln is 1 NVD entry which mentions X
  - ✓ NVD.Advice(X) : 1 vuln is 1 NVD entry which mentions X, and has a reference to an advisory confirmed by X's vendor
  - ✓ NVD.Bug(X) : 1 vuln is 1 NVD entry which mentions X, and has a reference to a bug confirmed by X's vendor
  - ✓ NVD.Nbug(X) : 1 vuln is 1 bug confirmed by X's vendor, and is referred to by 1 NVD entry mentioning X
  - ✓ Advice.Nbug(X) : 1 vuln is 1 bug confirmed by X's vendor, and is directly or indirectly referred to by an NVD entry mentioning X

Targets of Analysis

* Targets of Analysis: 17 releases of Browsers !!
  - ✓ IE: v4 – v8
  - ✓ Firefox: v1.0 – v3.6
  - ✓ Chrome: v1.0 – v6.0

* Why should they be browsers?
  - ✓ Complex enough (like a small operating system)
  - ✓ Quickly evolve
  - ✓ Targets of many attacks

* Why should they be IE, Firefox and Chrome?
  - ✓ Top three most popular browsers in the world

Data Collection

* Data sources
  - ✓ IE : NVD
  - ✓ Firefox : MFSA, Bugzilla, NVD
  - ✓ Chrome: ChromeIssue, NVD

* Data collection
  - ✓ 58 data sets of 17 releases

	nvd	nvd.Bug	nvd.Advice	nvd.Nbug	advice.Nbug	#Releases
Chrome	●	●	—	●	—	6 (v1.0–v6.0)
Firefox	●	●	●	●	●	6 (v1.0–v3.6)
IE	●	—	●	—	—	5 (v4.0–v8.0)

Bullets (●) indicate enabled data sets. Dashes (—), otherwise, mean there is no data sources available to collect the data sets.

Goodness of Fit (GoF) Analysis

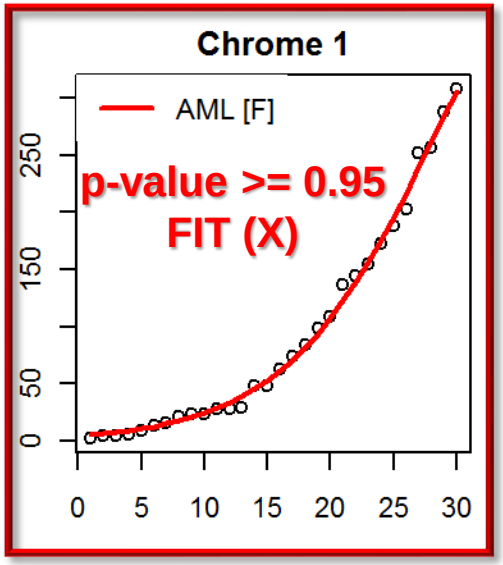
* Fit data to VDMs
  - ✓ Non-linear regression method, implemented in R (www.r-project.org)

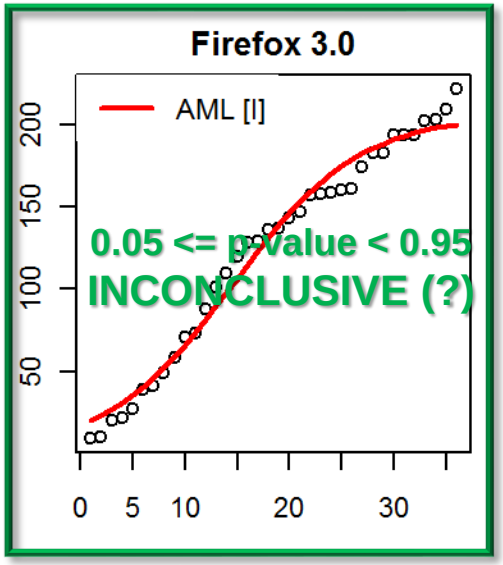
* Chi-square test for Goodness-of-Fit (GoF)
  - ✓ O_i – observed values
  - ✓ E_i – expected values

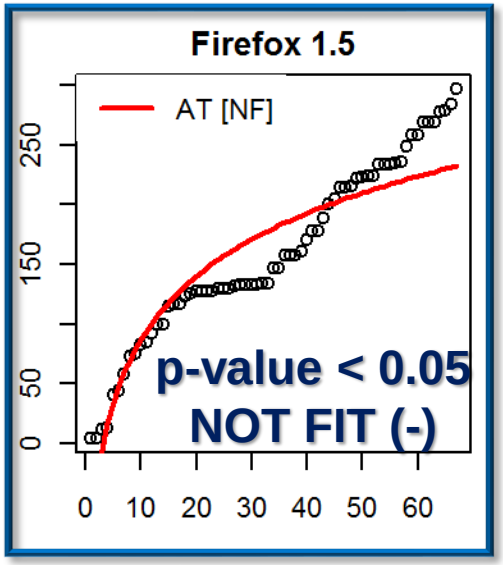
$$\chi^2 = \sum_{i=1}^{n} \frac{(O_i - E_i)^2}{E_i}$$

* The meaning of Chi-square test
  - ✓ Measure the difference between observed and expected values
  - ✓ Use p-value of the chi-square test to know whether VDM works or not

RQ1: Which VDM works, which doesn't?





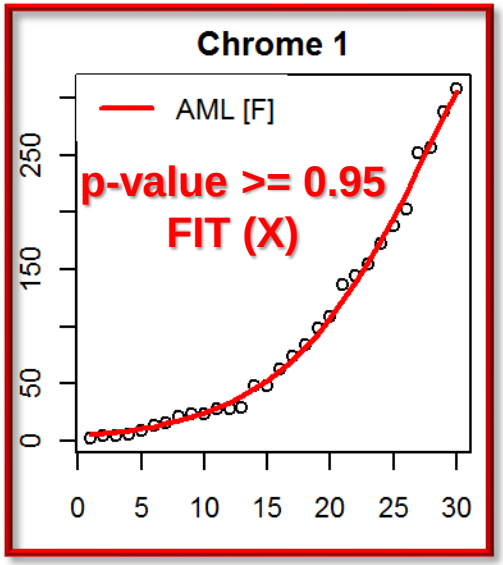


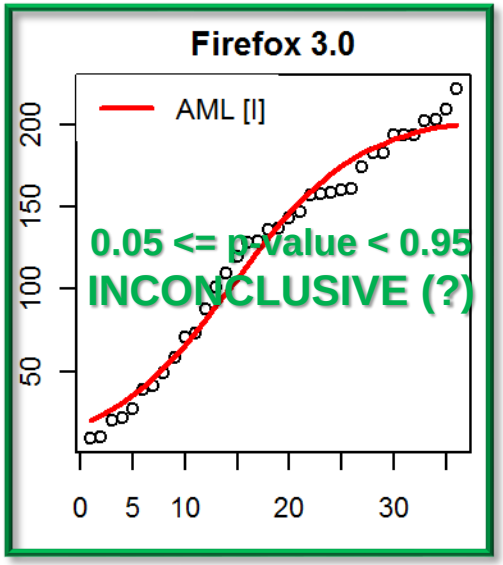
NVD Data set

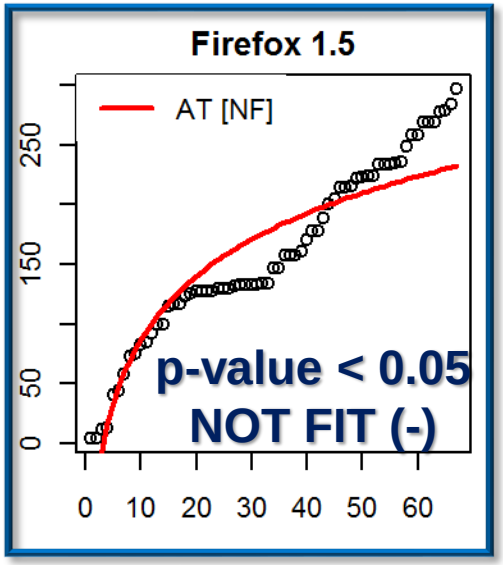
	Firefox						Chrome						IE				
Model	1.0	1.5	2.0	3.0	3.5	3.6	1.0	2.0	3.0	4.0	5.0	6.0	4.0	5.0	6.0	7.0	8.0
AML	–		?	?	?	?	X	?	?	?	?	?	X	?	?	–	X
AT	–	–	–		–	–	–	–	–	–	–	–	–	–	–	?	–
LN	–	–	X	–	X	?	–	–	–	?	–	–	–	–	–	?	?
LP	–	–	X	?	X	X	–	–	–	–	?	?	–	X	–	X	?
RE	–	–	X	?	X	X	–	–	–	–	?	?	–	X	–	?	?
RQ	–	–	–	?	?	X	–	–	?	?	?	?	–	–	–	–	X

The goodness of fit of a VDM is based on *p-value* in the χ^2 test. *p-value* < 0.05: not fit (–), *p-value* ≥ 0.95: good fit (X), and inconclusive fit (?) otherwise.

RQ1: Which VDM works, which doesn't?







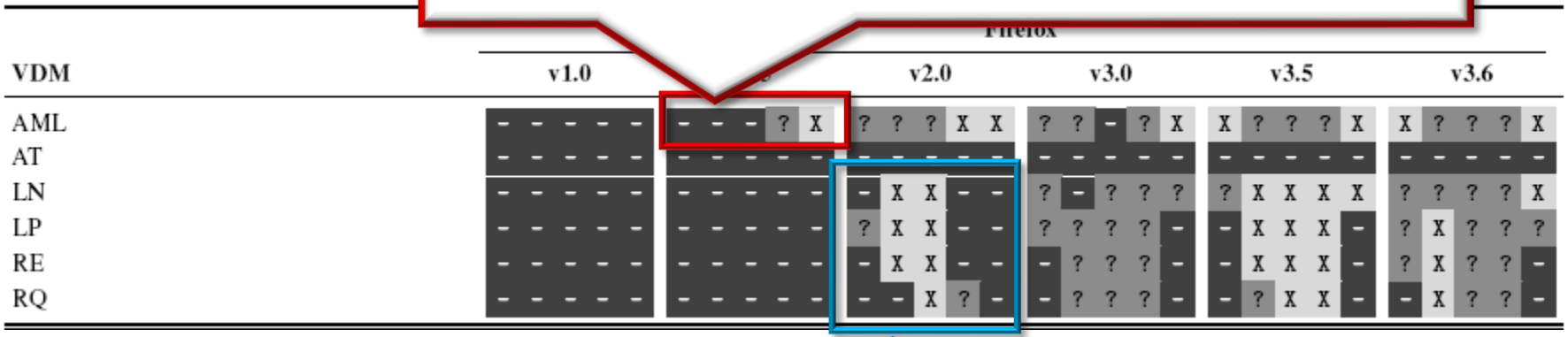
NVD Data set

Model	Firefox 1.0	Firefox 1.5	Firefox 2.0	Firefox 3.0	Firefox 3.5	Firefox 3.6	Chrome 1.0	Chrome 2.0	Chrome 3.0	Chrome 4.0	Chrome 5.0	Chrome 6.0	IE 4.0	IE 5.0	IE 6.0	IE 7.0	IE 8.0
AML	–	–	?	?	?	?	X	?	?	?	?	?	X	?	?	–	X
AT	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	?	–
LN	–	–	X	–	X	?	–	–	–	?	–	–	–	–	–	?	?
LP	–	–	X	?	X	X	–	–	–	–	?	?	–	X	–	X	?
RE	–	–	X	?	X	X	–	–	–	–	?	?	–	X	–	?	?
RQ	–	–	–	?	?	X	–	–	?	?	?	?	–	–	–	–	X

The goodness of fit of a VDM is based on *p-value* in the χ^2 test. *p-value* < 0.05: not fit (–), *p-value* ≥ 0.95: good fit (X), and inconclusive fit (?) otherwise.

RQ2: The Impact of Types of Data Set

Advice.Nbug, NVD, NVD.Advice, NVD.Bug, NVD.NBug



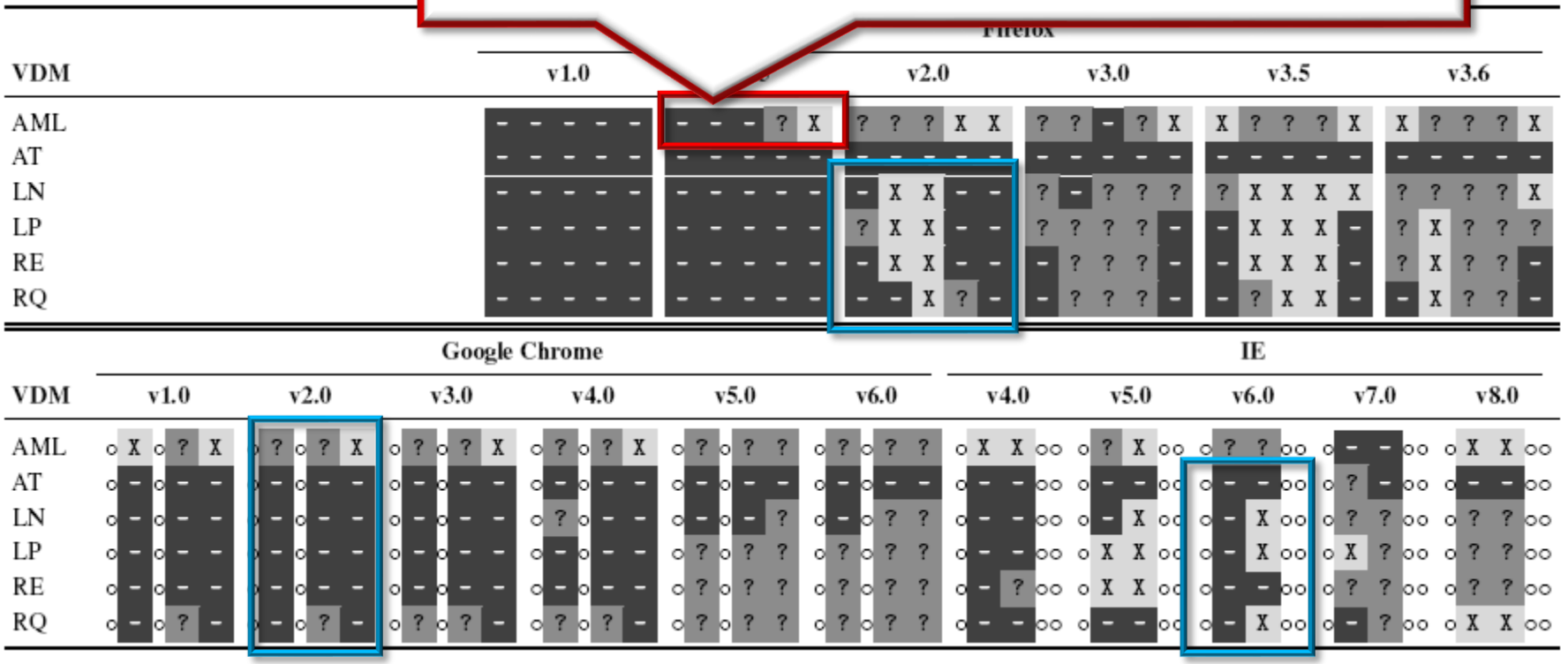
Each column has five cells corresponding to Advice.Nb… NVD.Advice, NVD.Bug, NVD.NBug

Opposite results for the same models

* Opposite results are obtained from different data sets
  - ✓ Same model
  - ✓ Same target (ie. same software release)
  - ✓ But different counting methods (diff. types of data set)

RQ2: The Impact of Data Sets

Advice.Nbug, NVD, NVD.Advice, NVD.Bug, NVD.NBug



Each column has five cells corresponding to Advice.Nbug, NVD, NVD.Advice, NVD.Bug, NVD.NBug

Opposite results for the same models

* Different types of data set would strongly impact to VDM's GoF

Conclusion and Future Work

- Summary
  - ✓ 6 VDMs are analyzed in 58 data sets of 17 browser releases
- The findings
  - ✓ VDM doesn't work: AT (for browsers)
  - ✓ VDMs (probably) don't work: LN, RQ (for browsers)
  - ✓ VDMs (probably) work: AML, LP, RE (for browsers)
  - ✓ Different types of data set would strongly impact to VDM's GoF
- Future work
  - ✓ How well could VDM predict the trend of vulns?
    - Split data sets in 2 parts: 1 for generating curves, 1 for testing
  - ✓ How VDM's GoF evolve overtime?
  - ✓ Which types of data set are more appropriate for VDM?
    - In terms of yielding more stable results

Thank you

Viet Hung Nguyen– vhnguyen@disi.unitn.it
Fabio Massacci – massacci@disi.unitn.it