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Fighting advanced malware using machine learning

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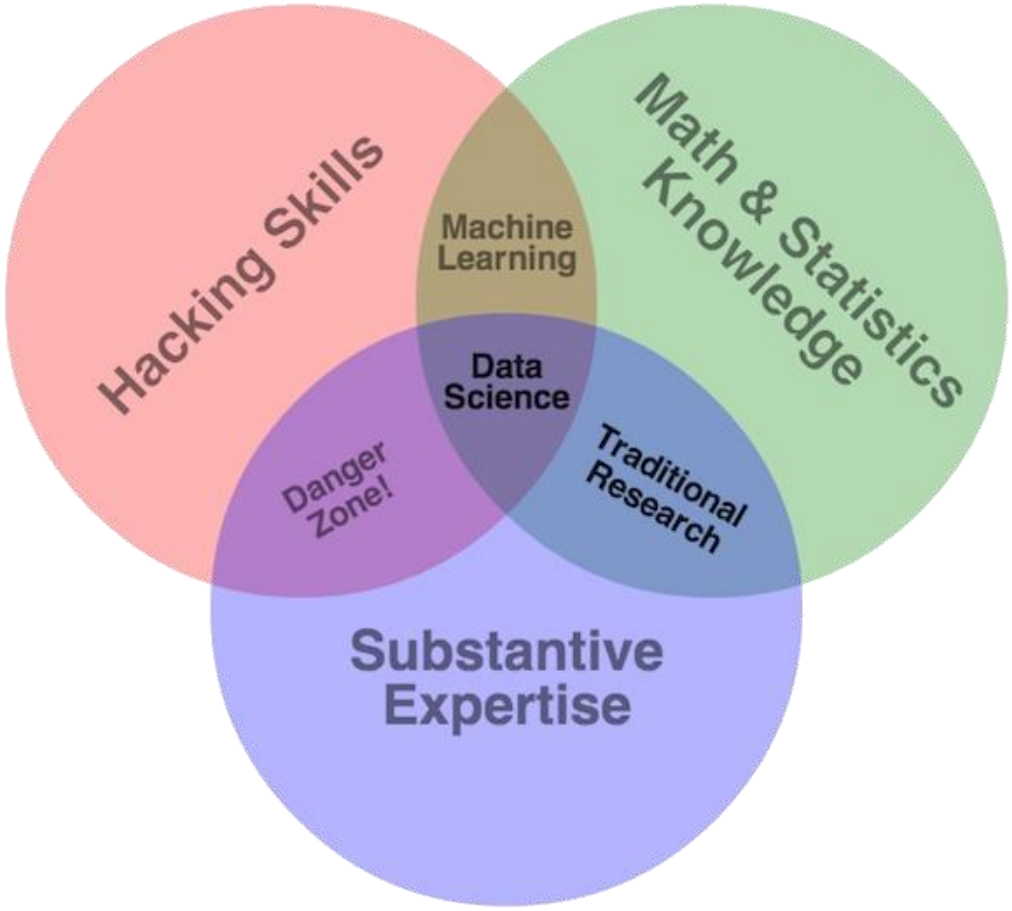
Who am I ?

- Security Researcher at FFRI, Inc
  - Malware and vulnerabilities analysis with RCE
  - Both Windows and Linux kernel development

- Speaker at
  - BlackHat USA/JP, RSA, PacSec, AVAR, etc.

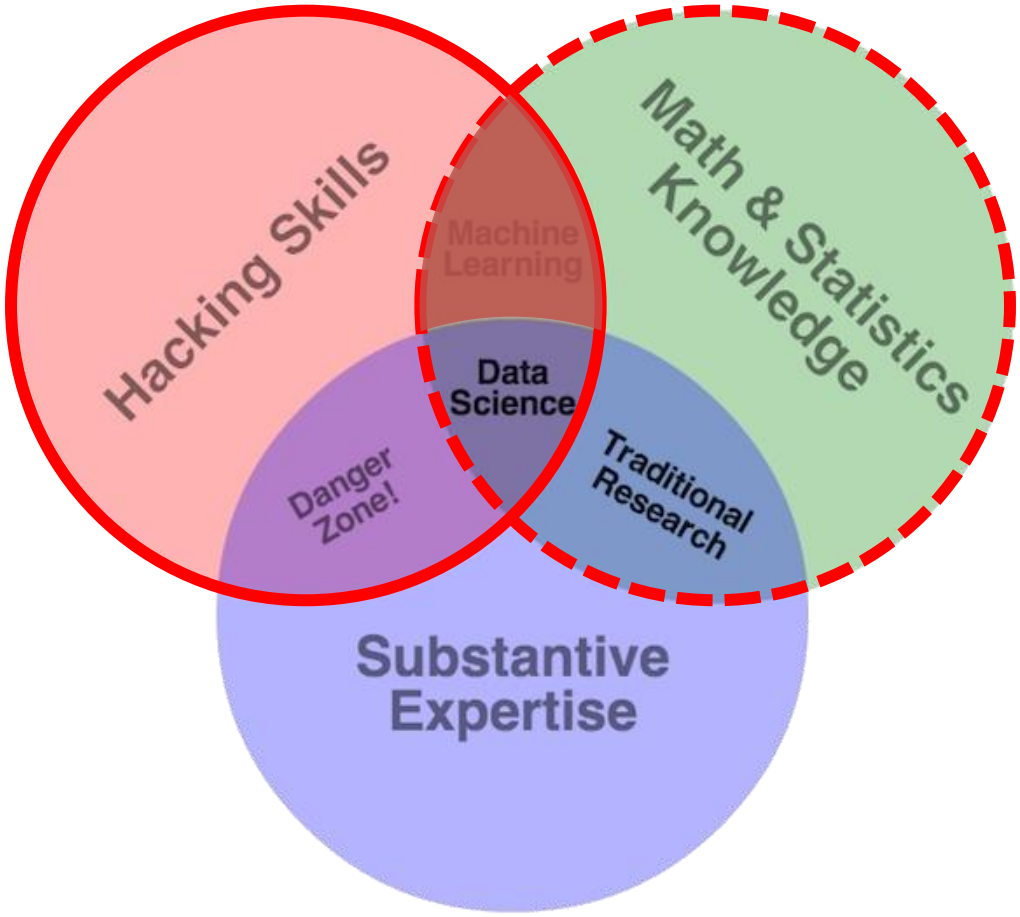
- *NOT* a MS/PhD degree in CS/Math
  - Just a user of machine learning

The Data Science Venn Diagram (in security)



http://www.niemanlab.org/images/drew-conway-data-science-venn-diagram.jpg

I am, and this talk is



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Agenda

- Background
- Our approach
- Future works
  - Computers vs. Man
  - Applying to real time protection
- Conclusion

Background – malware and its detection

Generators

Obfuscators

Increasing malware

Targeted Attack (Unknown malware)

Limitation of pattern matching

other methods

Reputation

Heuristic

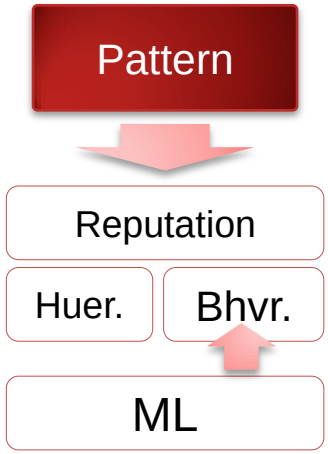
Behavioral

Machine learning

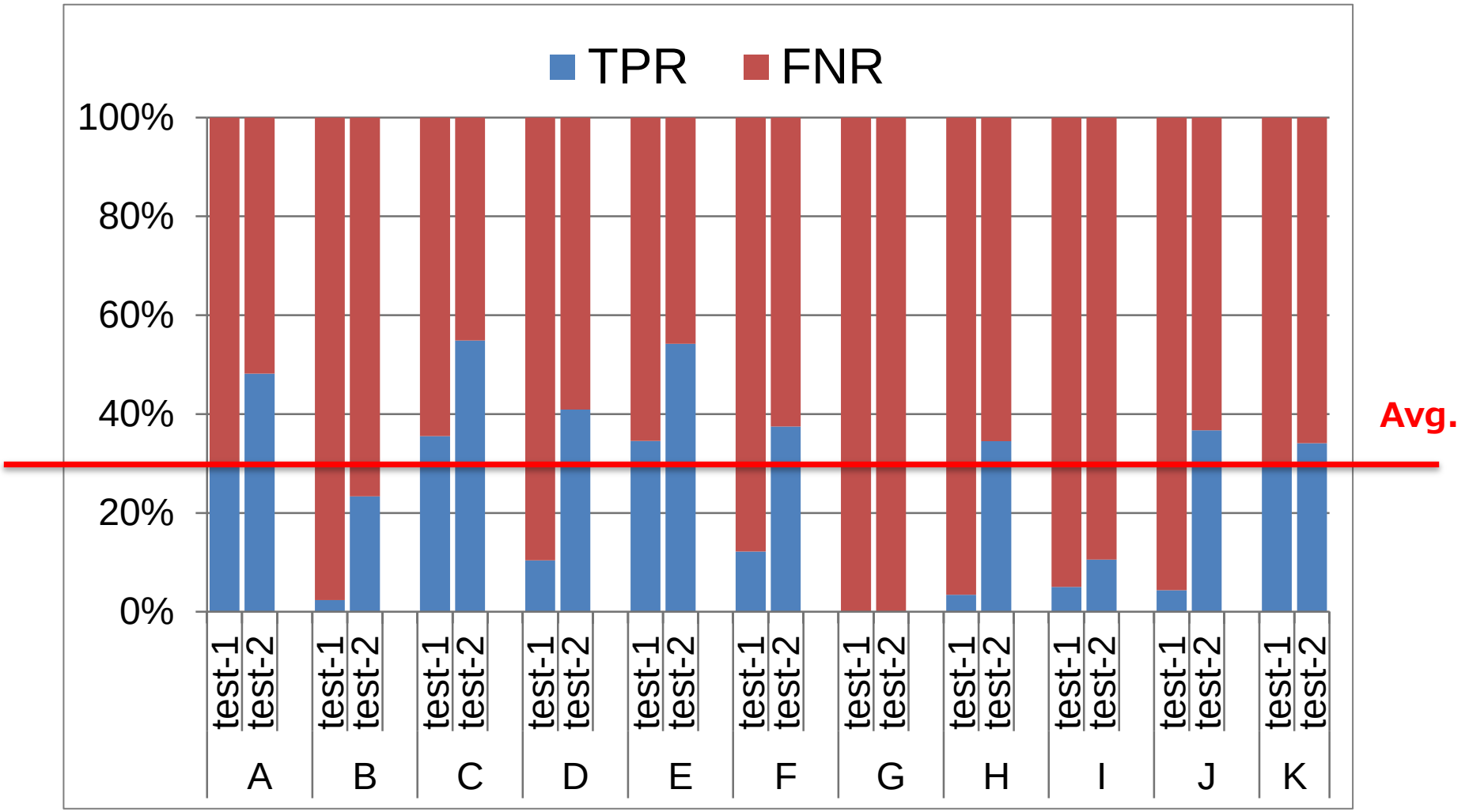
Bigdata

Limitation of signature matching

- Evaluated 11 AV-product's TRP using Metascan
- Used fresh malware (not wildlist malware)
- Prepared 2 test sets from different sources and period
  - test-1: 1,000 samples
  - test-2: 900 samples

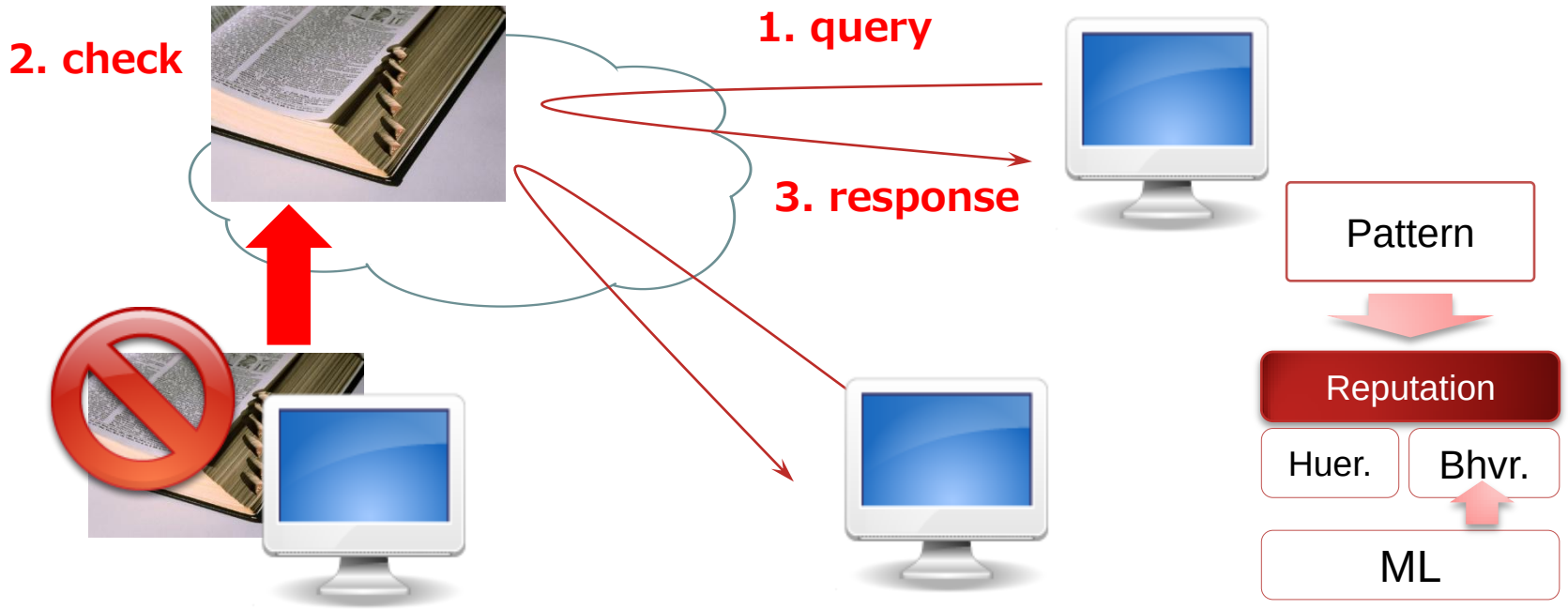


Limitation of signature matching



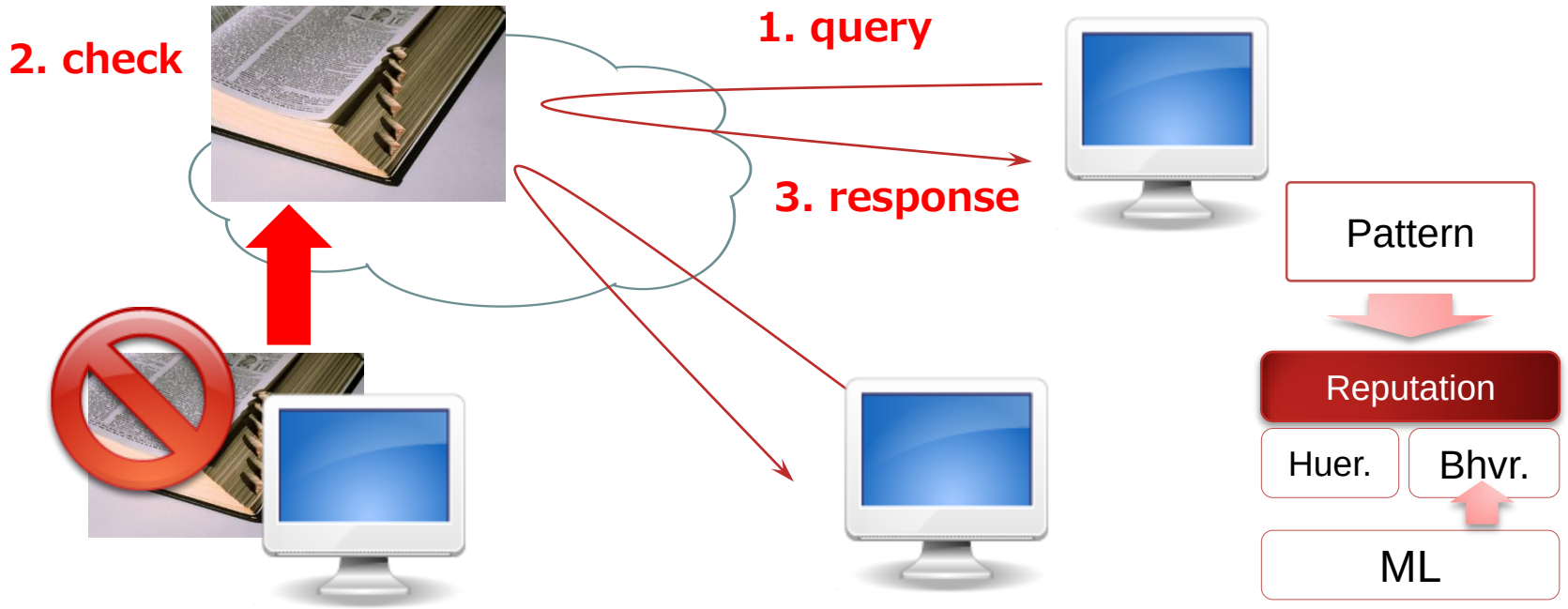
Advantage of (cloud) reputation

- Concept is the same with signature-matching(Blacklisting)
- Endpoints don't have to keep **HEAVY** patterns anymore
- Easy to reflect a new pattern to the others



Disdvantage of (cloud) reputation

- “Detectable” means that someone is already attacked
- What if you are the first victim?
- How much effective against “Targeted Attack” it is?

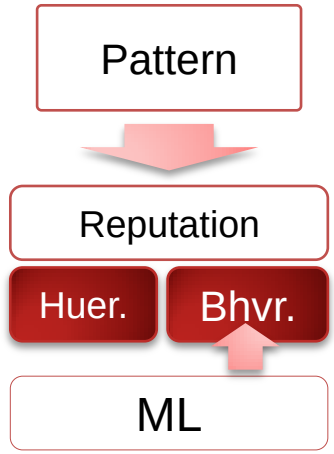


Advantage of heuristic/behavioral detection

- Based on pre-determined characteristics or behaviors
  - OpenProcess -> WriteProcessMemory -> CreateRemoteThread
  - Registering itself to auto start extensibility points
  - Disabling Windows Firewall, etc.

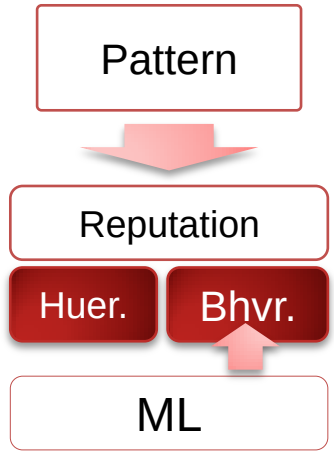
- Providing generic logics to detect malware

- Signature-free
  (eliminate regular scanning and update)



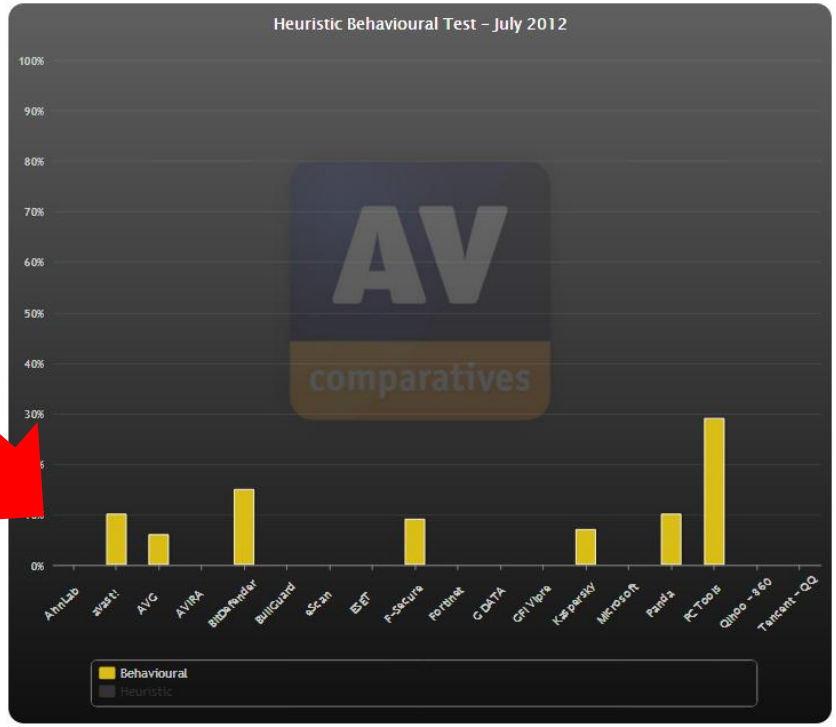
Disadvantage of heuristic/behavioral detection

- Difficult to avoid false positives completely
- Or ask user to determine if an action would be allow or not (User dependent)
- Have to analyze malware and update logics continuously (Not human task, more suitable for computers)



Heuristic Behavioral Test - July 2012

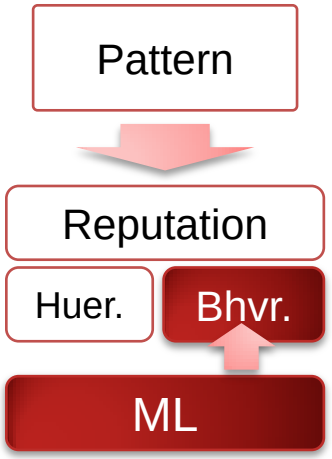
- AV-comparatives publishes H/B Test results since 2012
- The behavioral hardly contributes to detect (avg: 4.8%)



http://chart.av-comparatives.org/chart1.php

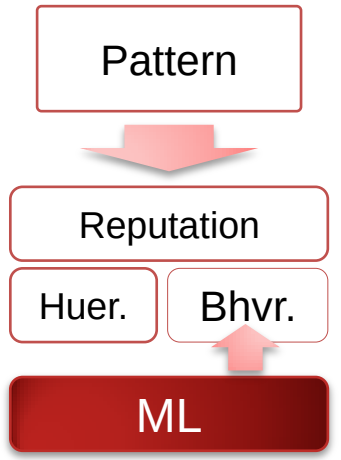
Our approach

- Behavioral-based detection powered by machine learning
- Not new but more practical for the industry
- Easy to try and automate using open source below
  - Cuckoo Sandbox
  - Jubatus



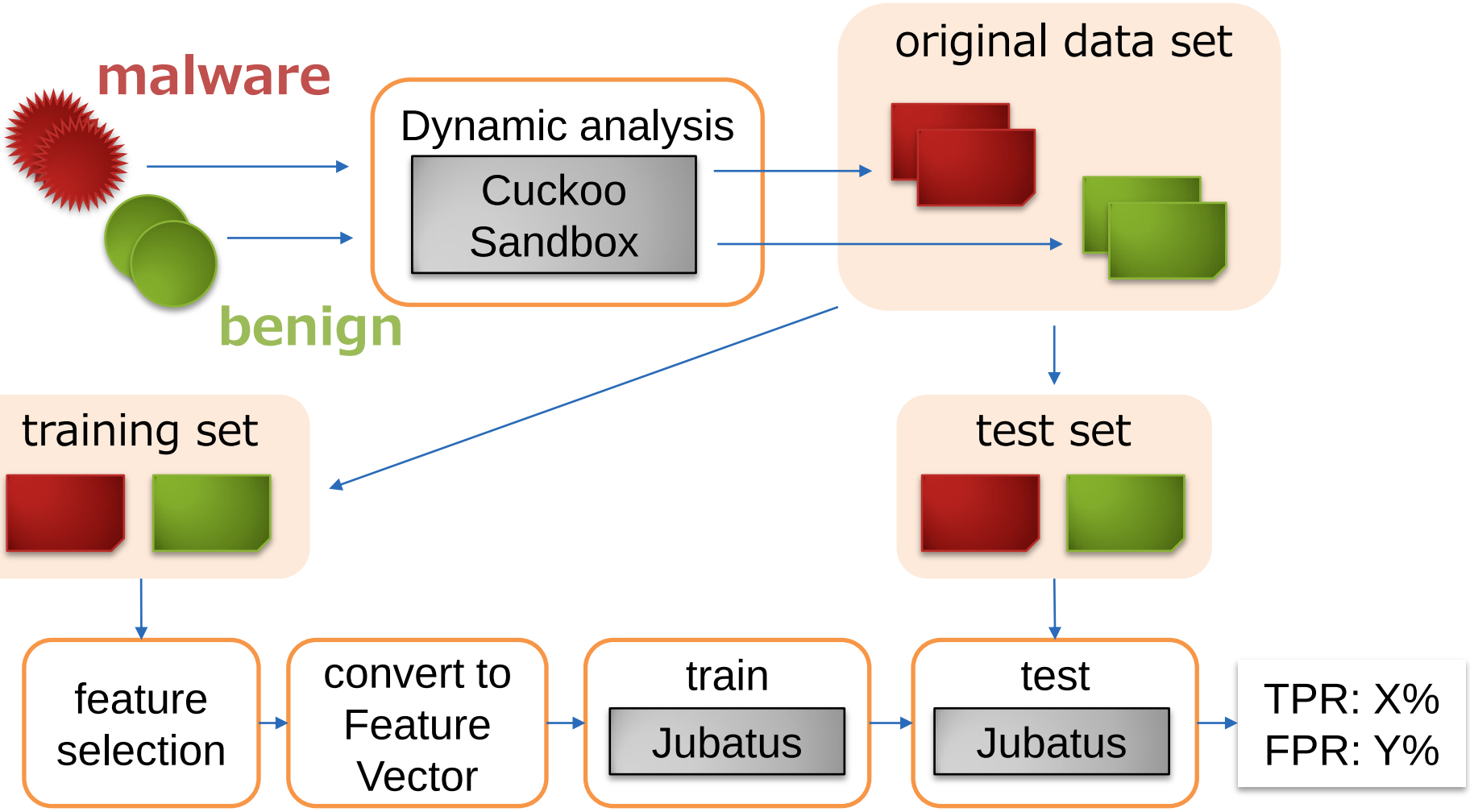
Machine learning-based detection

- Most research is doing in academic
- Basically, it is a classification problem (task)
- Mainly focusing on a combination of the factors below
- Some good results are reported



Features	Algorithms	Evaluation
Static information	SVM	TPR/FRP, etc.
Dynamic information	Naive bayes	Accuracy, Precision
Hybrid	Perceptron, etc.	ROC-curve, etc.

Overview

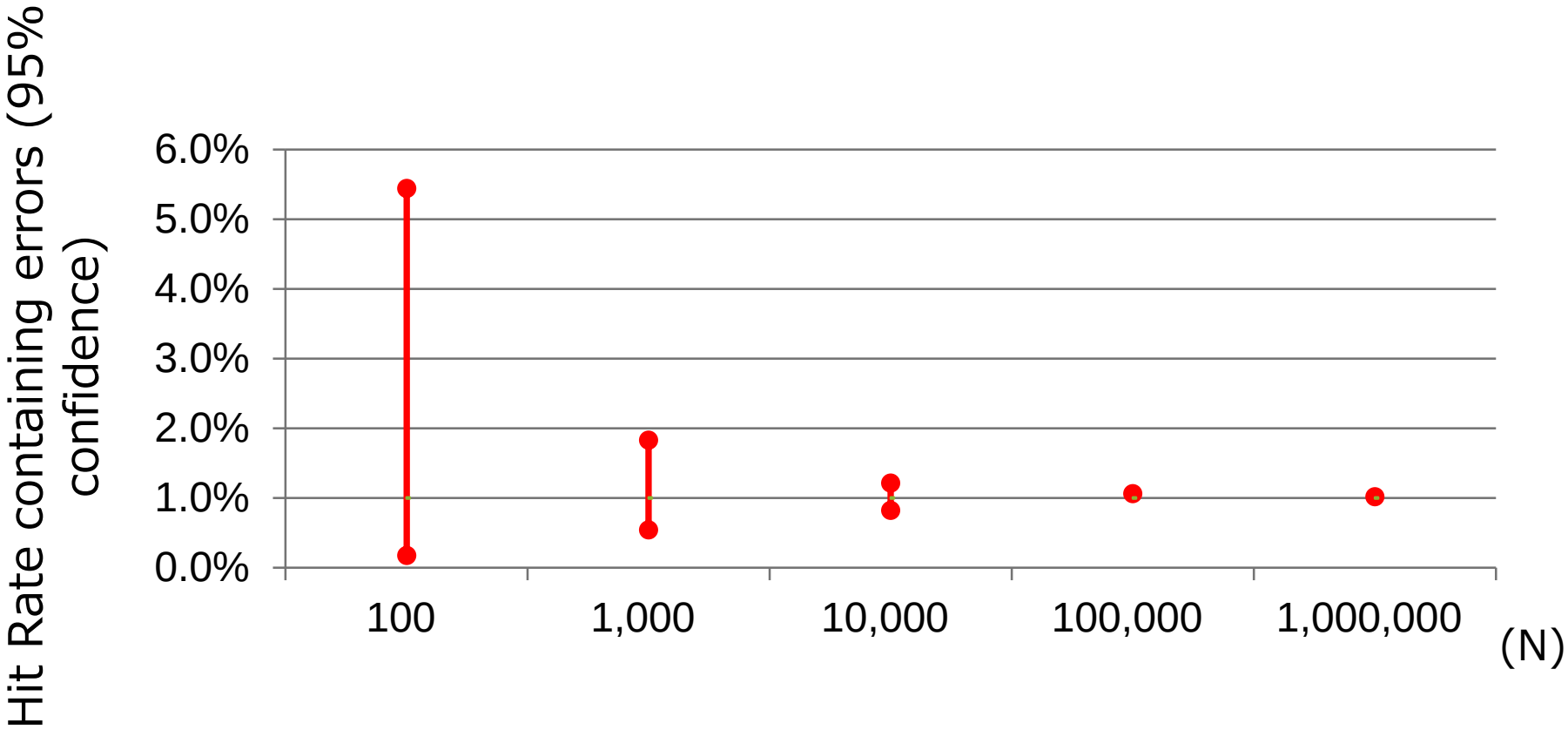

malware
benign
Dynamic analysis
Cuckoo Sandbox
original data set
training set
test set
feature selection
convert to Feature Vector
train
Jubatus
test
Jubatus
TPR: X%
FPR: Y%

How many samples should we use?

- It is a “Confidence Interval” theory
- It depends on how margin of error we accept
- All of these below hit rates are 1%
  - 1/100 (N=100)
  - 10/1,000 (N=1,000)
  - 100/10,000 (N=10,000)
- Each confidences for determining to “1%” are different
  - Each of them has different **error**

How many samples should we use?

- We can calculate estimation of margin of error based on N



Malware and benign files

- Randomly sampling from files collected by ourselves
  - Malware: 15,000(5,000 = training, 10,000 = testing)
  - Benign: 15,000 (5,000 = training, 10,000 = testing)

- *Random* is very important
  - Different period (choose 15,000/N sample from every day)
  - Different sources
  - Never care about filetype or malware type

Cuckoo Sandbox - http://www.cuckoosandbox.org/

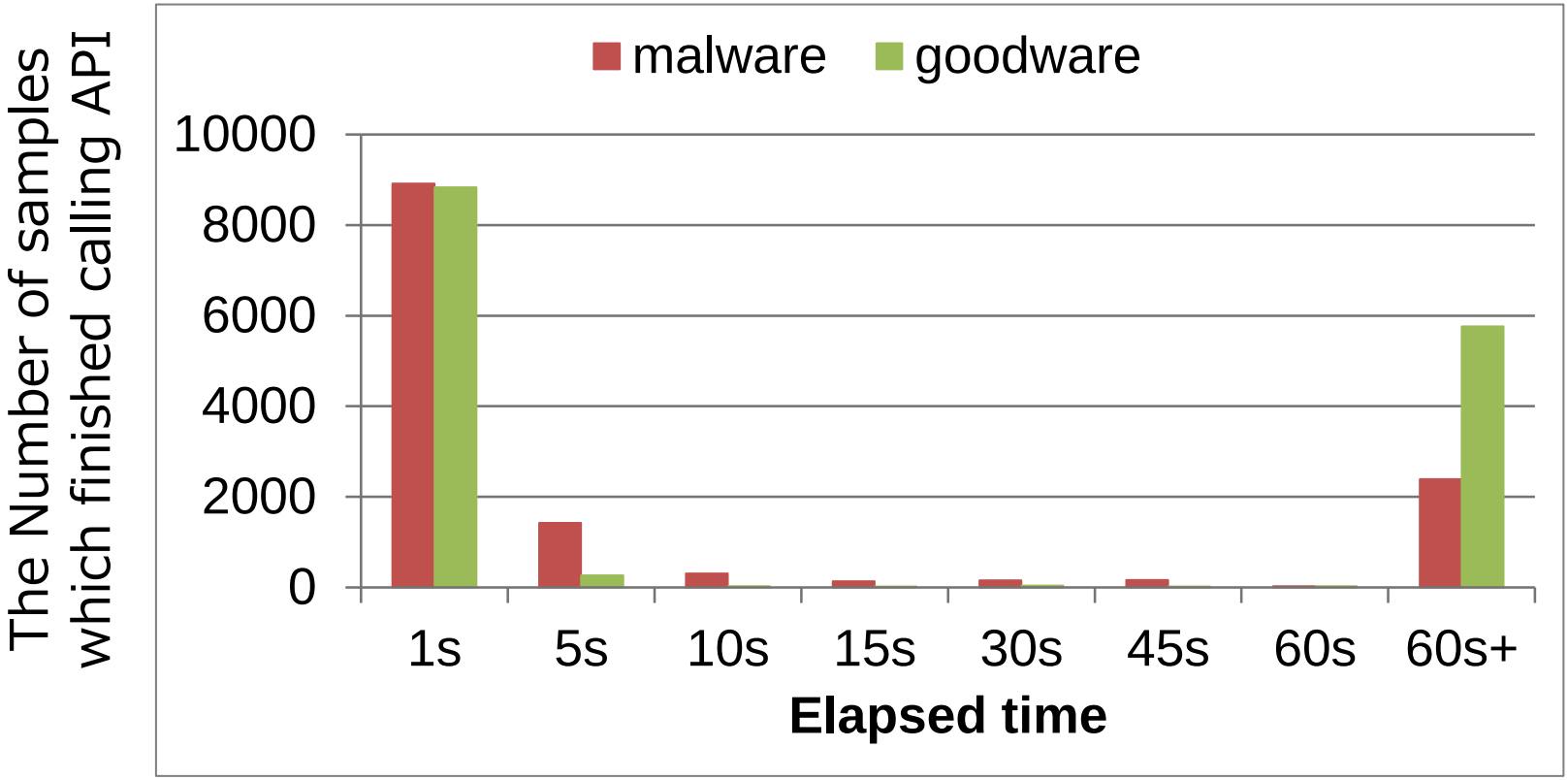
- Open source automated malware analysis system
  - Sending malware into a virtual machine from a host
  - Executing the malware inside the virtual machine
  - Monitoring and saving its behaviors at runtime
    - API calls, network activity, VT results, etc.

API calls


```
"calls": [
    {
        "category": "system",
        "status": "FAILURE",
        "return": "0xc0000135",
        "timestamp": "2013-02-28 12:03:49,478",
        "thread_id": "420",
        "repeated": 0,
        "api": "LdrLoadDll",
        "arguments": [
            { "name": "Flags", "value": "1242916" },
            { "name": "FileName", "value": "C:¥¥WINDOWS¥¥system32¥¥VB6JP.DLL" },
            { "name": "BaseAddress", "value": "0x00000000" }
        ]
    },
    {
        "category": "registry",
        "status": "SUCCESS",
        "return": "0x00000000",
        "timestamp": "2013-02-28 12:03:49,528",
        "thread_id": "420",
        "repeated": 0,
        "api": "NtOpenKey",
        "arguments": [
            { "name": "KeyHandle", "value": "0x00000058" },
            { "name": "DesiredAccess", "value": "1" },
            { "name": "ObjectAttributes", "value": "Registry¥¥MACHINE¥¥System¥¥Curre
        ]
    },
```

Trends of API calls

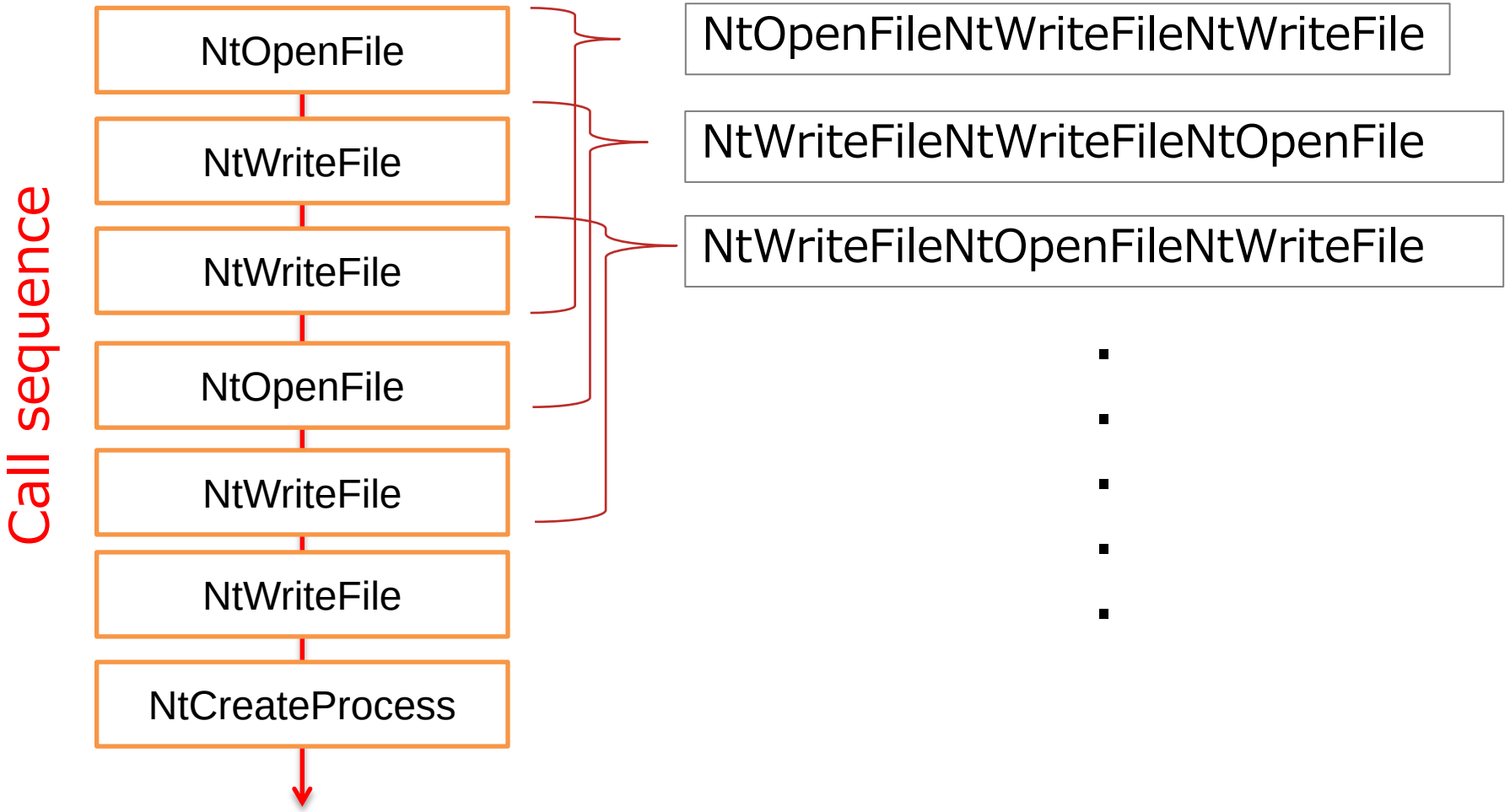
- Most of the samples finished calling API within 1s (or keep calling APIs) -> Used API only called within 5s



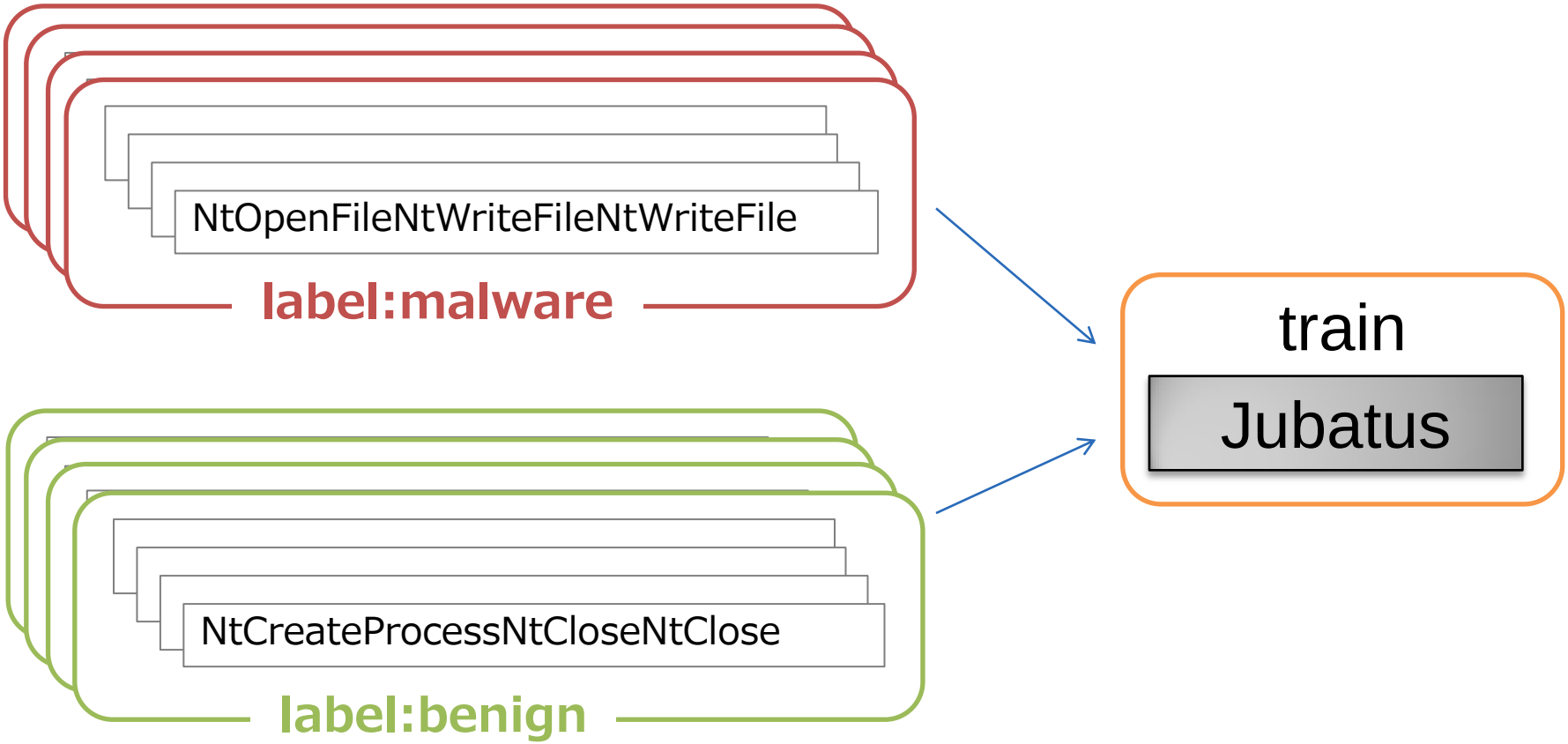
Jubatus - http://jubat.us/en/

- Distributed Online Machine Learning Framework
  - Distributed: Scalable
  - Online: Not batch, continuous learning
- Open source, LGPL v2.1. Latest release is 0.4.5(22/07/2013)
- Developed by Preferred Infrastructure, Inc. and NTT Software Innovation Center
- Support various machine learning
  - Classification, Regression, Recommendation, Anomaly Detection
- Easy to use (many language bindings, feature converter, etc)

Feature selection and convert to FV



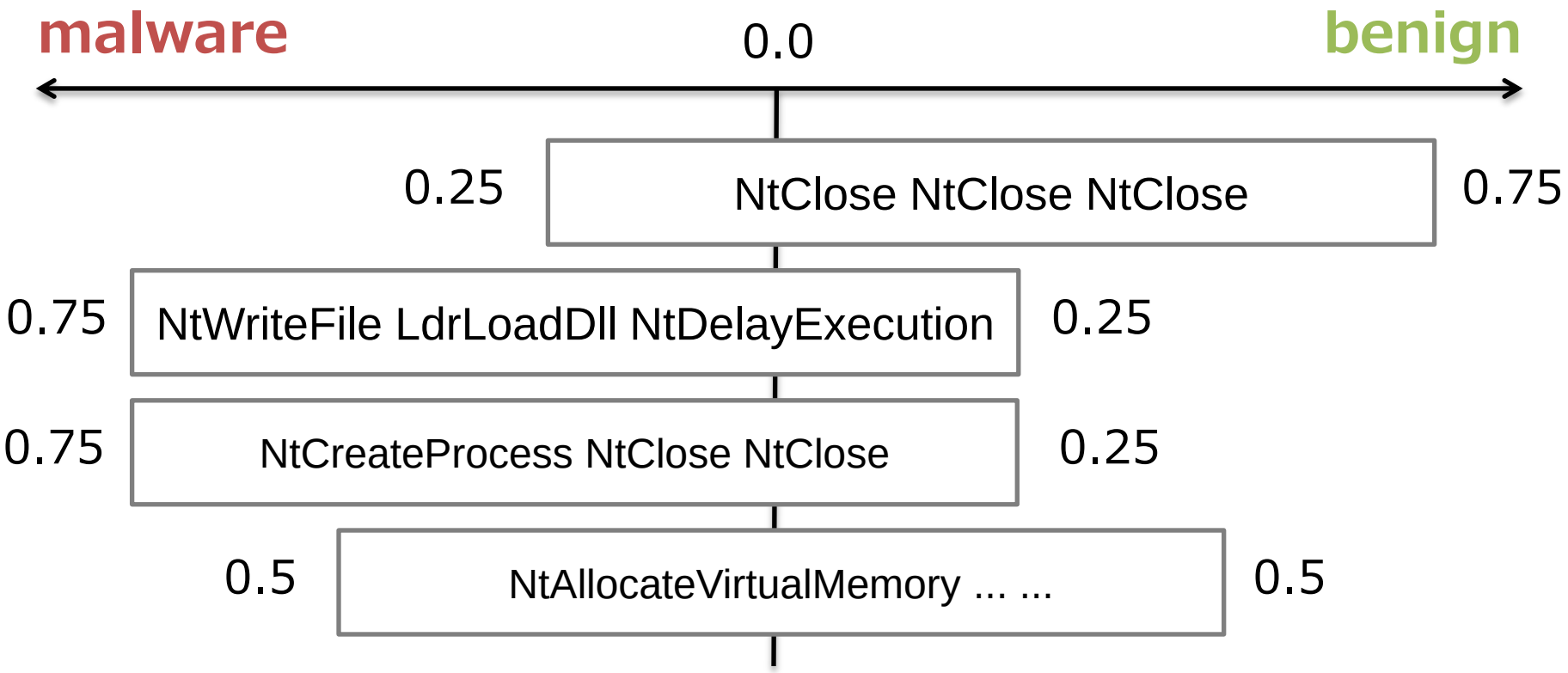
Feature selection and convert to FV



(Image) Training internal

Calc and update each FV's weight based on its freq. and label

(for the detail is dependent on the algorithm called **AROW**, don't ask me :-)



Testing results

- N of N-gram
  - 3~5-gram > 2-gram = 6-gram
- Best: 3-gram
  - TRP: 72.33% [71.58 ~ 73.07 % (95% confidence)]
  - FPR: 0.77% [0.60 ~ 0.99% (95% confidence)]
- The result above is an example
  - A lot of combination of features are available (we used only “API-name” and its sequence)

Demo

Future Works

Dumping training model

- http://blog.jubat.us/2013/06/classifier.html (Japanese only)

Investigating weight parameters of classifier

jubalocal_storage_dump.cpp
https://gist.github.com/t-abe/5746333

Indicators of malware likeness in API 3-gram

```
[foo@nolife classifier]$ ./dump   --input  model   --label  "malware"
0.181128        api_call$VirtualProtectEx_VirtualProtectEx_VirtualProtectEx@space#log_tf/bin
0.142254        api_call$RegOpenKeyExA_NtOpenKey_NtOpenKey@space#log_tf/bin
0.137144        api_call$NtReadFile_NtReadFile_NtFreeVirtualMemory@space#log_tf/bin
0.134443        api_call$LdrLoadDll_LdrGetProcedureAddress_VirtualProtectEx@space#log_tf/bin
0.130287        api_call$LdrLoadDll_RegOpenKeyExA_NtOpenKey@space#log_tf/bin
0.130287        api_call$DeviceIoControl_LdrLoadDll_RegOpenKeyExA@space#log_tf/bin
0.122363        api_call$VirtualProtectEx_LdrLoadDll_LdrGetProcedureAddress@space#log_tf/bin
0.102545        api_call$NtFreeVirtualMemory_LdrGetDllHandle_NtCreateFile@space#log_tf/bin
0.102485        api_call$RegCloseKey_RegCloseKey_RegCloseKey@space#log_tf/bin
0.0983165       api_call$NtReadFile_NtFreeVirtualMemory_LdrLoadDll@space#log_tf/bin
0.0966545       api_call$NtSetInformationFile_NtReadFile_NtFreeVirtualMemory@space#log_tf/bin
0.094639        api_call$NtMapViewOfSection_NtFreeVirtualMemory_NtOpenKey@space#log_tf/bin
0.0933827       api_call$NtFreeVirtualMemory_LdrLoadDll_LdrGetProcedureAddress@space#log_tf/bin
0.0905402       api_call$DeviceIoControl_DeviceIoControl_NtWriteFile@space#log_tf/bin
0.0903766       api_call$DeviceIoControl_NtWriteFile_NtWriteFile@space#log_tf/bin
0.0884724       api_call$RegOpenKeyExW_RegOpenKeyExW_LdrGetDllHandle@space#log_tf/bin
0.0853282       api_call$LdrLoadDll_LdrLoadDll_LdrLoadDll@space#log_tf/bin
...
```

Indicators of goodware likeness in API 3-gram

```
[foo@nolife classifier]$ ./dump   --input  model   --label  "goodware"
0.268353        api_call$LdrGetDllHandle_LdrGetDllHandle_ExitProcess@space#log_tf/bin
0.268353        api_call$LdrGetDllHandle_ExitProcess_NtTerminateProcess@space#log_tf/bin
0.259838        api_call$NtWriteFile_LdrGetDllHandle_LdrGetDllHandle@space#log_tf/bin
0.25887 api_call$NtWriteFile_NtWriteFile_LdrGetDllHandle@space#log_tf/bin
0.135514        api_call$NtOpenFile_NtOpenFile_NtCreateFile@space#log_tf/bin
0.122445        api_call$DeviceIoControl_LdrLoadDll_LdrGetProcedureAddress@space#log_tf/bin
0.12242 api_call$DeviceIoControl_DeviceIoControl_LdrGetDllHandle@space#log_tf/bin
0.119231        api_call$GetSystemMetrics_LdrLoadDll_NtCreateMutant@space#log_tf/bin
0.115319        api_call$DeviceIoControl_LdrGetDllHandle_LdrGetProcedureAddress@space#log_tf/bin
0.109306        api_call$LdrGetProcedureAddress_NtOpenKey_LdrLoadDll@space#log_tf/bin
0.105579        api_call$NtReadFile_NtReadFile_NtReadFile@space#log_tf/bin
0.104565        api_call$NtCreateFile_NtCreateFile_NtWriteFile@space#log_tf/bin
0.103304        api_call$RegOpenKeyExA_LdrGetDllHandle_LdrGetProcedureAddress@space#log_tf/bin
0.10306         api_call$VirtualProtectEx_RegOpenKeyExA_LdrGetDllHandle@space#log_tf/bin
0.100701        api_call$NtFreeVirtualMemory_NtFreeVirtualMemory_GetSystemMetrics@space#log_tf/bin
...
```

Computer vs. Man

- "VirtualProtectEx_VirtualProtectEx_VirtualProtectEx" looks like to related to malware
- How about "RegOpenKeyExA_NtOpenKey_NtOpenKey"?
- Computers might recognize indicators which human can't (Extremely strong left-brain player)
- Why don't we cooperate with machine?

Using computers

- Generating models using computers
- Checking them and guessing new logics by human (Using our right-brain)
- ML-based detection is sometimes difficult to control
  - Cannot specify strict conditions to detect

“ It is detected because ML said so ! ”

- Hybrid of ML-based and Logic-based would be powerful

Applying to real time protection

- Using static information as feature
  - We can check a file before its execution
  - The performance is dependent on features

- Using dynamic information as feature
  - Malware is already executed
  - Sometimes, detections would be too late
  - The hybrid detection above might be also useful in this perspective

Conclusion

- Traditional pattern-matching reaches its limit
- Current behavioral detections hardly contributes to detect
- By applying ML to behavioral detections
  - TPR is improved
  - Computers recognize new features which human can't
  - We should make use of them

Thank you!

Contact: research-feedback@ffri.jp
Twitter: @FFRI_Research