Mobile device security or MADAM: A Multi Level Anomaly Detector for Android Malware

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Joint work with Andrea Saracino, Daniele Sgandurra, Gianluca Dini, Francesco Mercaldo …

Outline

- National Research Council of Italy in a nutshell
- Security for mobile devices (android)
- Madam framework
- Future work

CNR in a nutshell

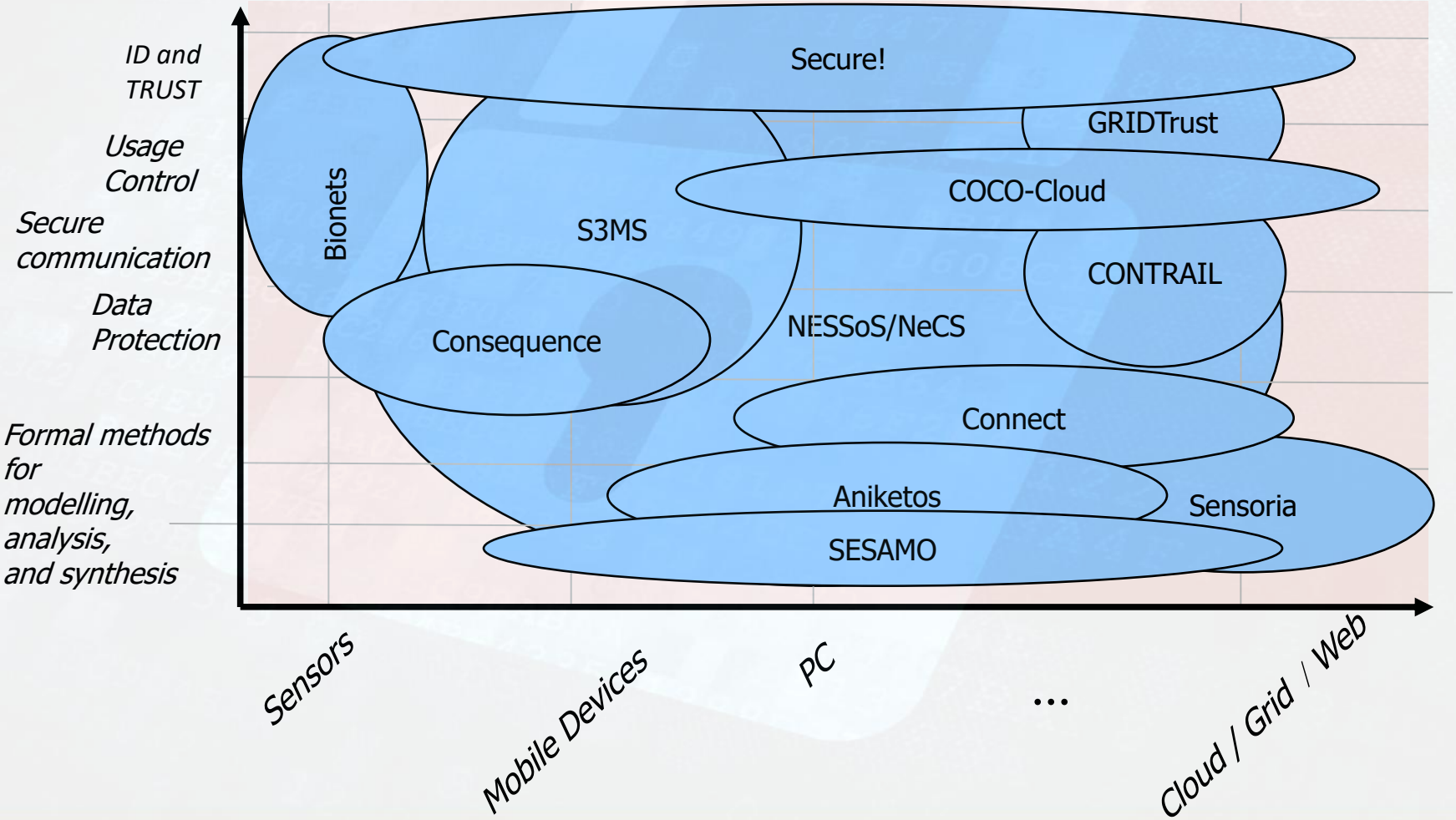
- The Italian National Research Council is the main public research organization in Italy
  - CNR has near 9000 employees split in:
    - 100 research Institutes
  - The main Italian organization as capability to attract EU project funding

- My Institute of informatics and Telematics (IIT-CNR)
    - Location: Pisa, Tuscany, Italy.
    - Has 4 research groups:
      - Security, networking, Algorithms, Web technologies
    - IIT-CNR manages the ccTLD ".it" and it is part of EURid consortium that manages ".eu"

- Fabio Martinelli is the coordinator of all the cyber security activities at CNR

- Security Group of IIT-CNR:
  - 6 researchers
  - 4 Post-docs
  - 3 PhD students
  - 1 Administrative
  - 4 software engineers
  - 3 associate researchers from University

EU projects/ Research Areas

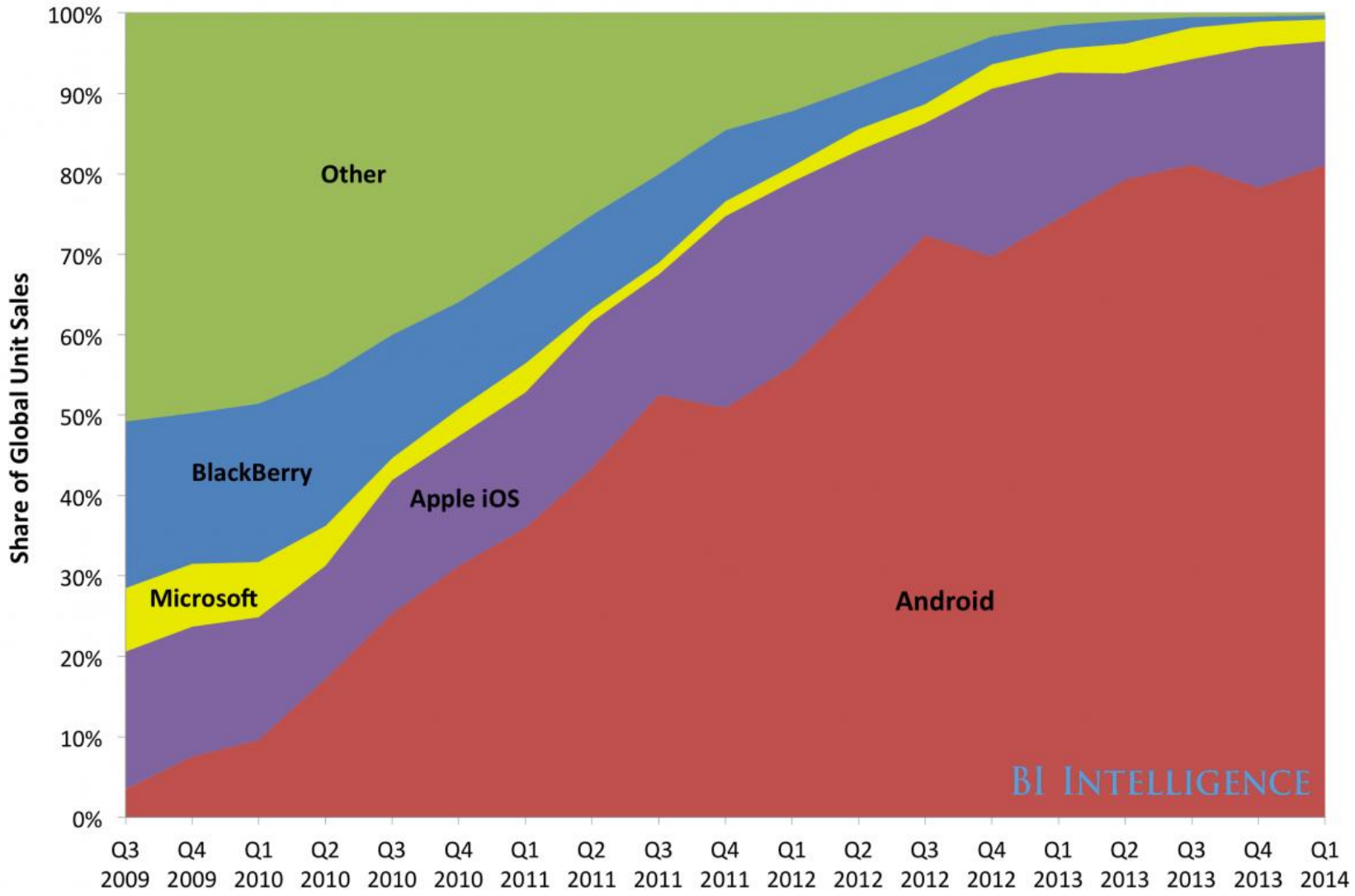


Current Main Activities

- Developing an promoting the **European Cyber Security Strategic Research Agenda** produced by the European Commission promoted Public Private Platform for Network and Information Security (NIS)
  - I am the coordinator of the WG3 on secure ICT research and innovation
    - More than 200 researchers from all the main research/academic/governmental institutions
  - Current Agenda is available at the ENISA URL:
    - https://resilience.enisa.europa.eu/nis-platform/shared-documents/wg3-documents
  - Agenda is taken as basis the cPPP on cyber security

- Coordination of the **European Research and Training Network in Cyber Security** (NeCS)
  - More than 12 partners
  - The objectives if to create an active community of PhD/young post docs students interested
  - Research and training opportunities
  - Fellowships in several European countries (including CNR in Italy) and travel available for young students

Global Smartphone Market Share By Platform

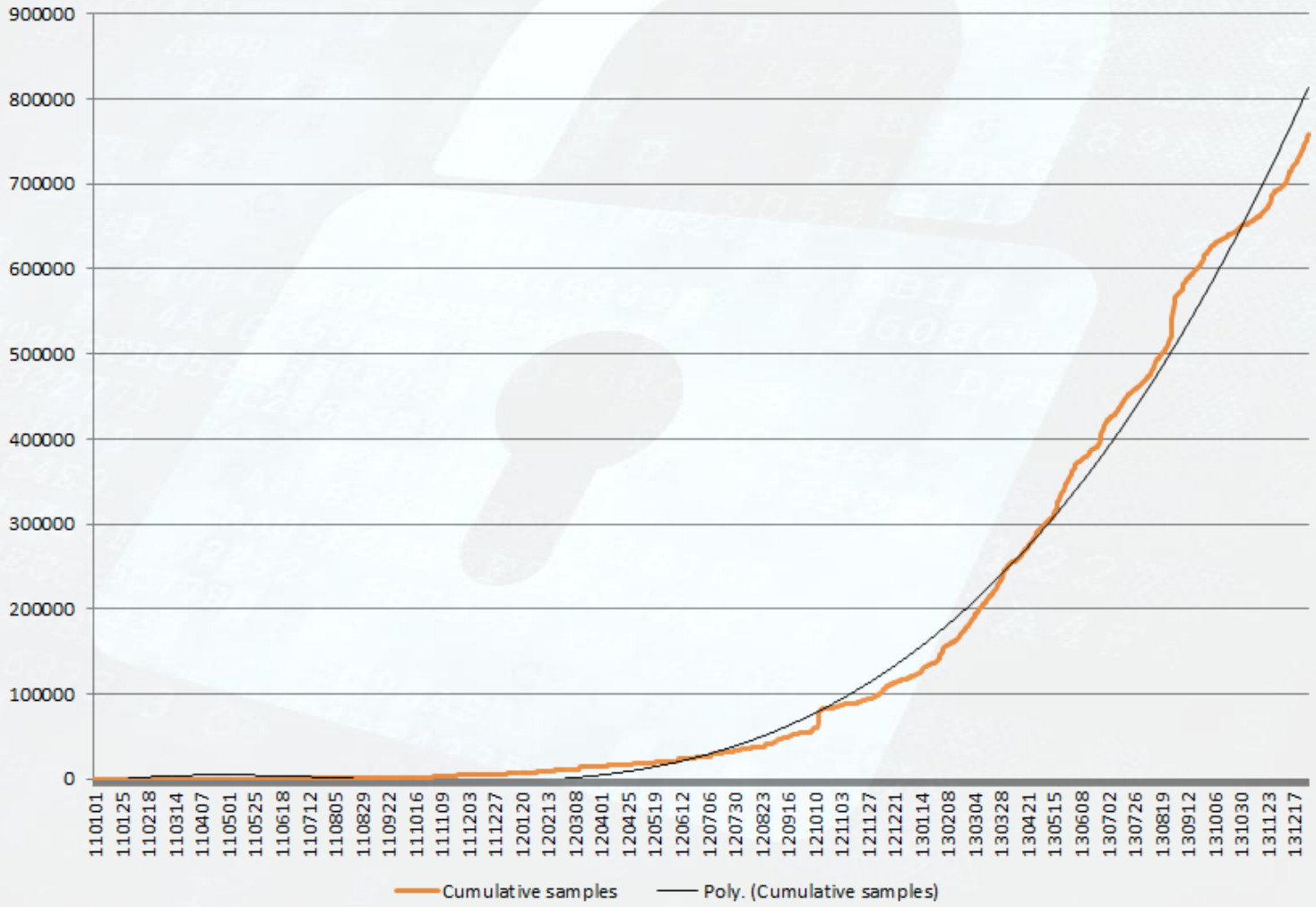


Source: IDC, Strategy Analytics

Security

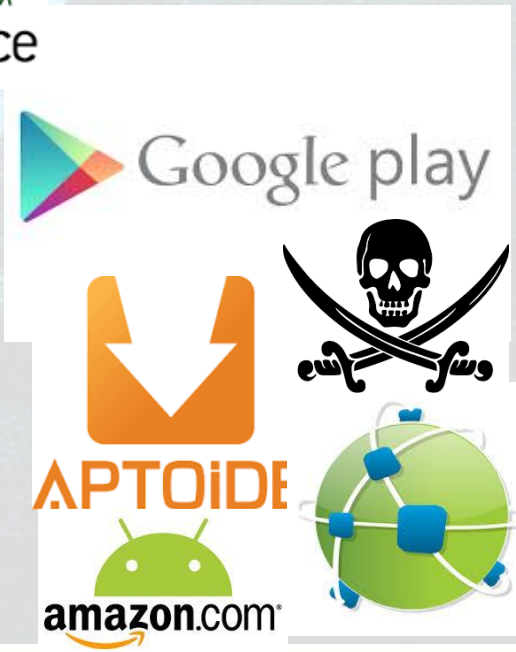
- Android is the target of 99% of security attacks on mobile devices.
- Apps are practically the main vector to bring security attacks on Android.
- Yearly malware increase: exponential

Malware Increase on Android



Why Android

- Not enough yet?
  - Android is **Open Source**
  - Availability of unofficial market



Android Markets

- Installing applications from unknown sources.
- Free versions of apps which have a cost on the official market.
- Limited-to-no control on the applications.
- Repackaged apps
  - Trojanized apps

Android Markets (2)

- Dangerous and malicious applications have been found **even** on the official market (Google Play).
  - Loose controls (*Bouncer)* not effective against zero day attacks.
  - Policy of forced removal of malicious apps from victim's devices.

Android Security State of the Art

- Producer Side:
  - Native Security Mechanisms:
    - App Isolation
    - Permission System (access control)
    - Blocking unknown sources by default
    - Online detection of malicious apps at install time (online antivirus).
  - Pro: Native, no overhead.
  - Cons: Easy to deceive

Android Security State of the Art (2)

- Commercial Side:
  - Anti-Virus code base – signature based.
    - Pretty much as standard computer AVs.
    - Also same brands -> Mobile edition
  - Pro:
    - Ease of use and no false positives
  - Cons:
    - Uneffective against new threats (zero day)

Android Security State of the Art (3)

- Research Side:
  - Static analysis framework
    - Decompiles and analyzes security relevant features of app code.
    - Pro: Can be run offline and almost accurate.
    - Cons: Attack specific and could miss run time misbehaviors
  - Information flow analysis
    - Detection of privacy leakage and app vulnerability
    - Example: Taintdroid
    - Pro: Effective in finding exploitable vulnerabilities.
    - Cons: Mainly concern only the subset of privacy related attacks

Android Security State of the Art (4)

- Still more research:
  - Security policies enforcement
    - Code instumentation-based (Example: App Guard).
    - Pro: Fine grained control.
    - Cons: Require modification of device OS.
  - Behavior based Intrusion Detection System:
    - Monitor and classify behaviors as genuine or malicious at runtime.
    - Pro: Can detect zero days.
    - Cons: Can raise False Positives

Detecting Malicious Behaviors

- Works at runtime.
- Code independency:
  - Not tricked by obfuscation
  - Not tricked by polymorphic malware
  - Not tricked by malware which download malicious code at runtime.

Malicious Behaviors

- Steal privacy sensitive data
  - Contacts
  - Text messages
- Steal user's money
  - Send text message
  - Register to premium services
  - Try to intercept bank transactions
- Show undesired advertisements (spam)
- Take control of the mobile device
- …

Malware: Some Numbers

- Almost 1 M malicious apps in the wild.
- More than 200 different malware families.
  - *Family: Different applications with the same malicious code.*

- *Finding:* Several implementations for the same misbehavior

Malware Classes

- **Malware Class**: *Different applications with different malicious code, performing however the same (or very similar) misbehavior.*
- 7 Malware classes identified… out of 150 analyzed families.

Malware Classes (2)

- ***SMS Trojan***: *Send SMS messages without user authorization.*
- ***Rootkit***: Attempt to take super user privileges.
- ***Botnet***: Open a backdoor and wait for commands from a C&C server.
- ***Spyware***: Steal sensitive information related to user privacy.

Malware Classes (3)

- ***Installer***: Try to download and install additional malicious applications, without the user authorization.
- ***Ransomware***: Attempt to take control of the device, blocking it till a fee is not paid by the user.
- ***Trojan***: The few families (5/125) with custom misbehaviors not falling in anyone of the former categories.

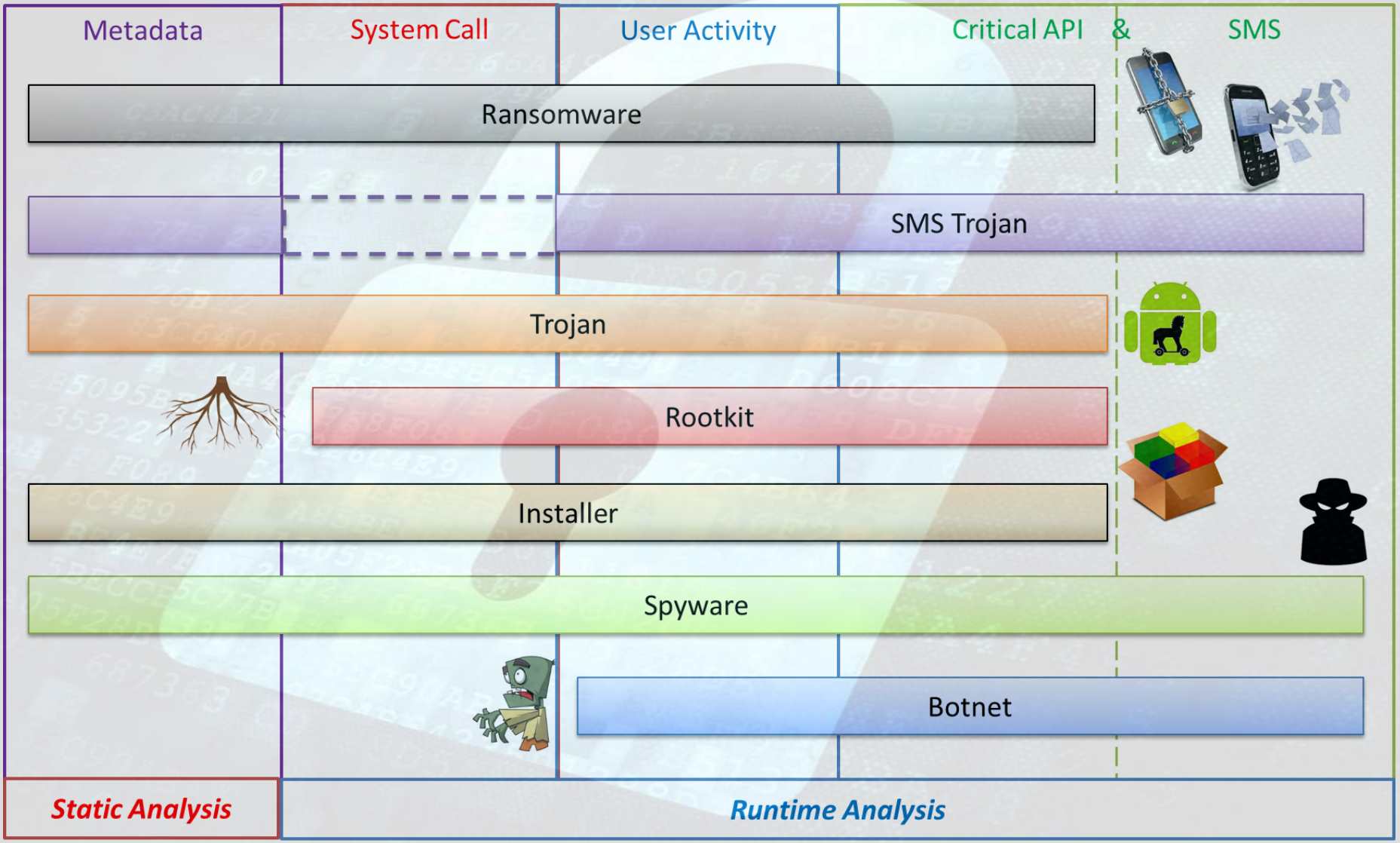
MADAM

- **Multi-Level Anomaly Detector for Android Malware**

  – It combines several approaches:
    - Anomaly Based Intrusion Detection and Prevention System.
    - Host based.
    - White list.
    - Zero day attacks.

Multi-Level for Higher Detection

- MADAM monitors 5 sets of features.
- Each set as standalone or in cooperation with others is used to spot a specific misbehavior class.


Metadata
System Call
User Activity
Critical API & SMS
Ransomware
SMS Trojan
Trojan
Rootkit
Installer
Spyware
Botnet
Static Analysis
Runtime Analysis

Global Analysis

- Monitor device at different levels:
  - System Calls
    - 13 SysCalls relevant
  - API Calls
    - Outgoing SMS
    - Active processes
    - Package installation
  - User Activity
    - User Present / Not Present

Per App Analysis

- Issued System Calls
- Sent Text Messages
  - Recipient
  - Message text
  - Frequency
- Number of processes per package
- Static Information
  - Required permissions
  - Market of provenance
  - Developer reputation
  - Rating and user feedbacks
  - Code analysis (n-grams)

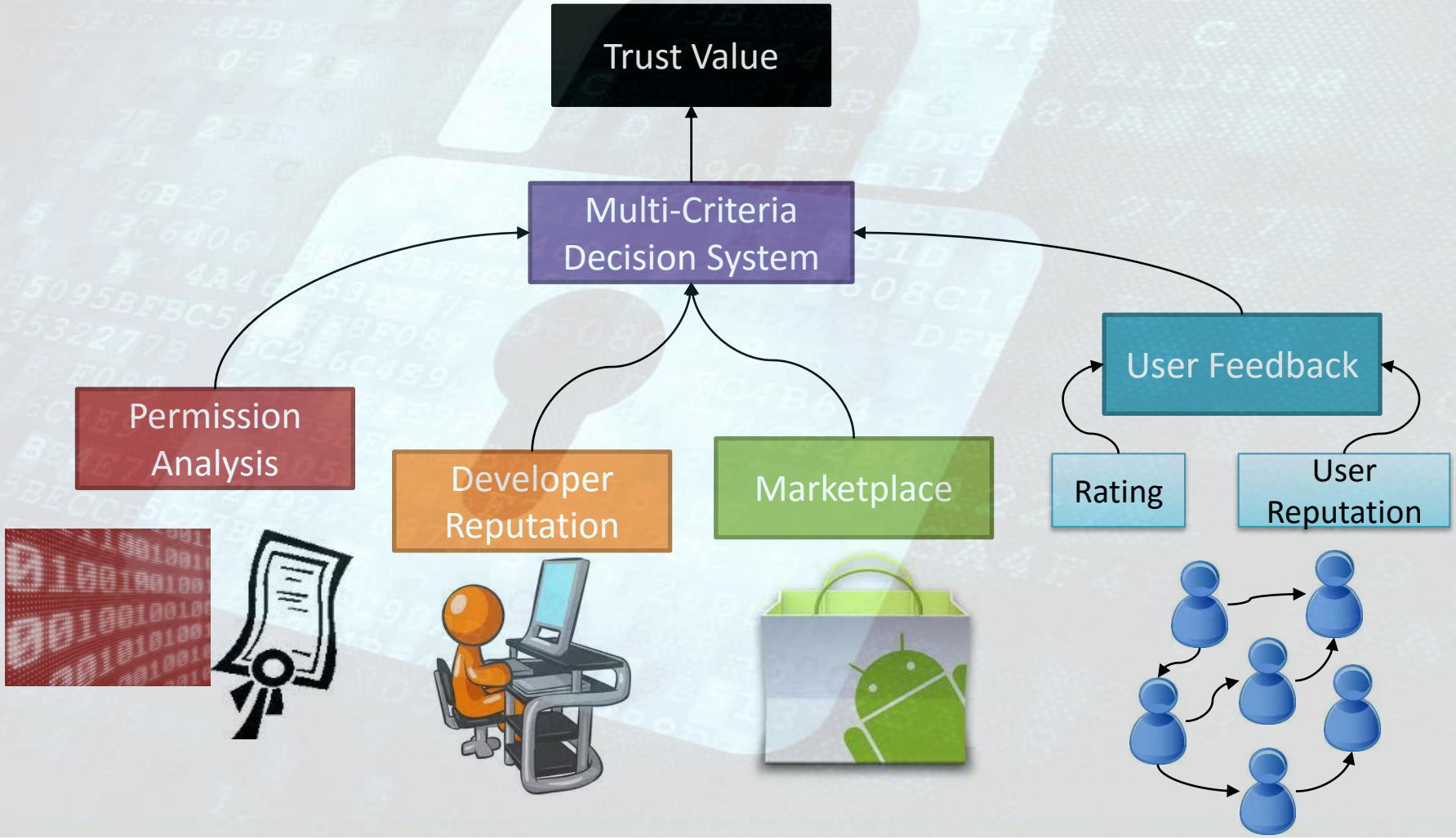
Static Analysis

- Performed at *deploy time*, before app can be executed.
- Controls app installed from any sources (not deceived by Installer malware).
- Analysis of app metadata.
  - Does not require to decompile binaries.
  - Low performance overhead.
- Analysis of n-grams (code analysis)

Static Analysis (2)

- N-grams analysis: analysis of frequencies of opCode n-grams (sequences of actions) to be used as features for classifiers.
- Classifier trained with known malicious frequencies.
- Application for static recognition of malicious apps.

Static Analysis (2)



Static Analysis (3)

- Permission analysis:
  - Extracted from *Manifest* file of APKs (`AndroidManifest.xml`)
  - Threat score assigned to each permission on three parameters:
    - Privacy Threat
    - Financial Threat
    - System Threat

Privacy Threat

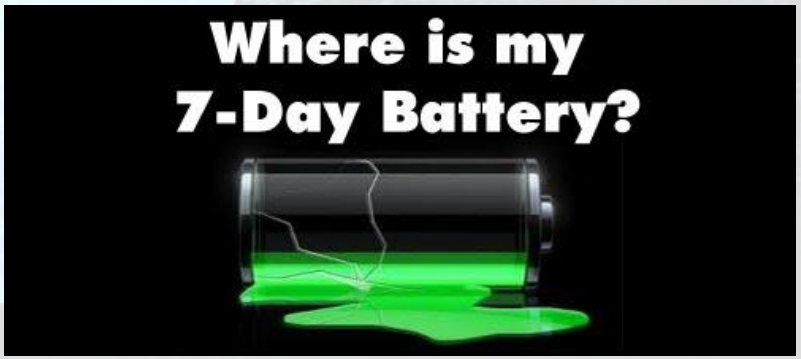
- Permissions that allow an application to:
  - Read Contacts
  - Read text messages
  - Access user's accounts and passwords
  - Read IMEI and location

Financial Threat

- Permissions that allow an application to:
  - Perform phone calls.
  - Send SMS messages.
  - Use the internet connection.
  - Modify connection settings.

System Threat

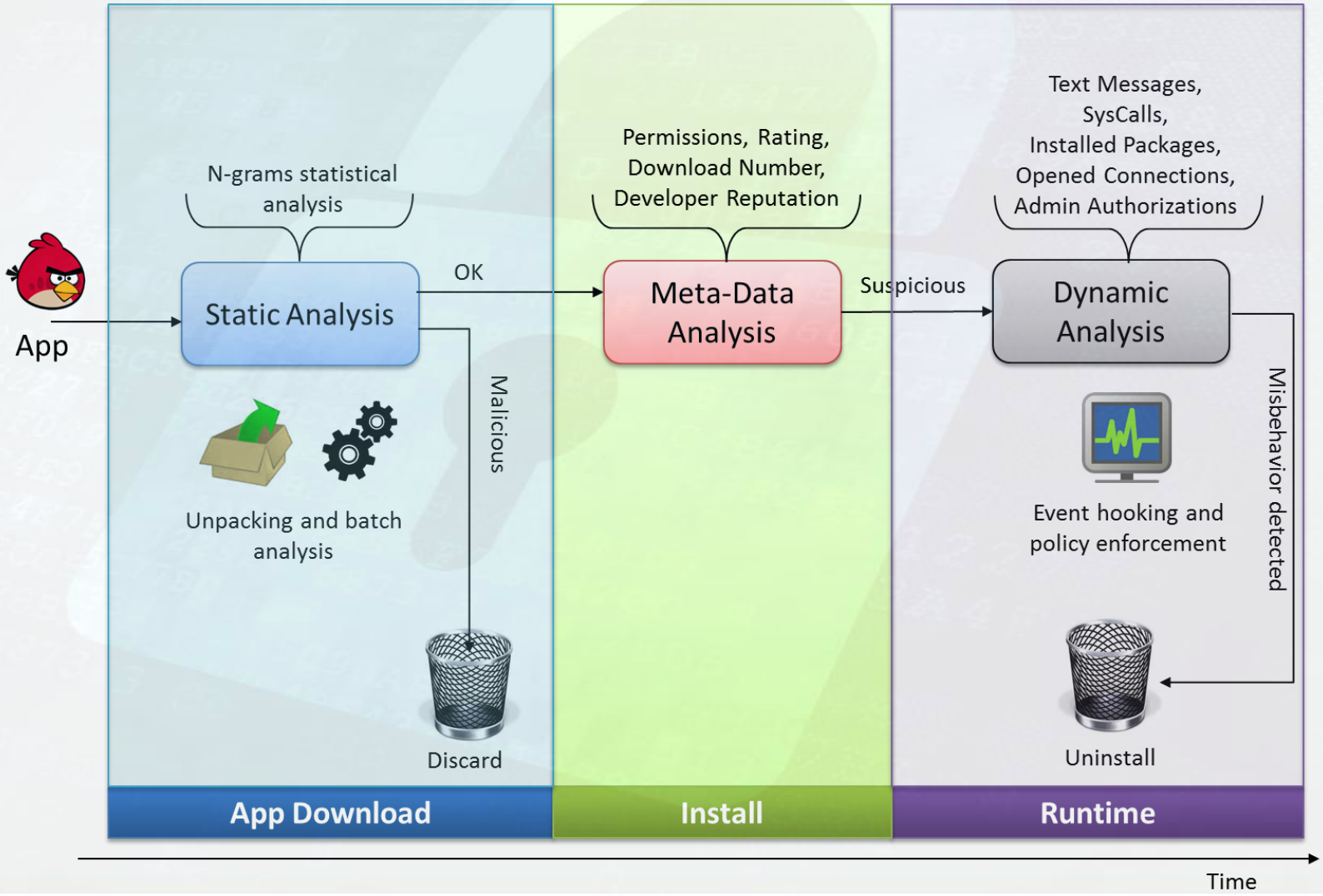
- Permissions that allow an application to:
  - Install/Uninstall applications on the phone.
  - Enable/Disable connection interfaces (Wi-Fi, Bluetooth, …).
  - Switch on/off the smartphone screen.



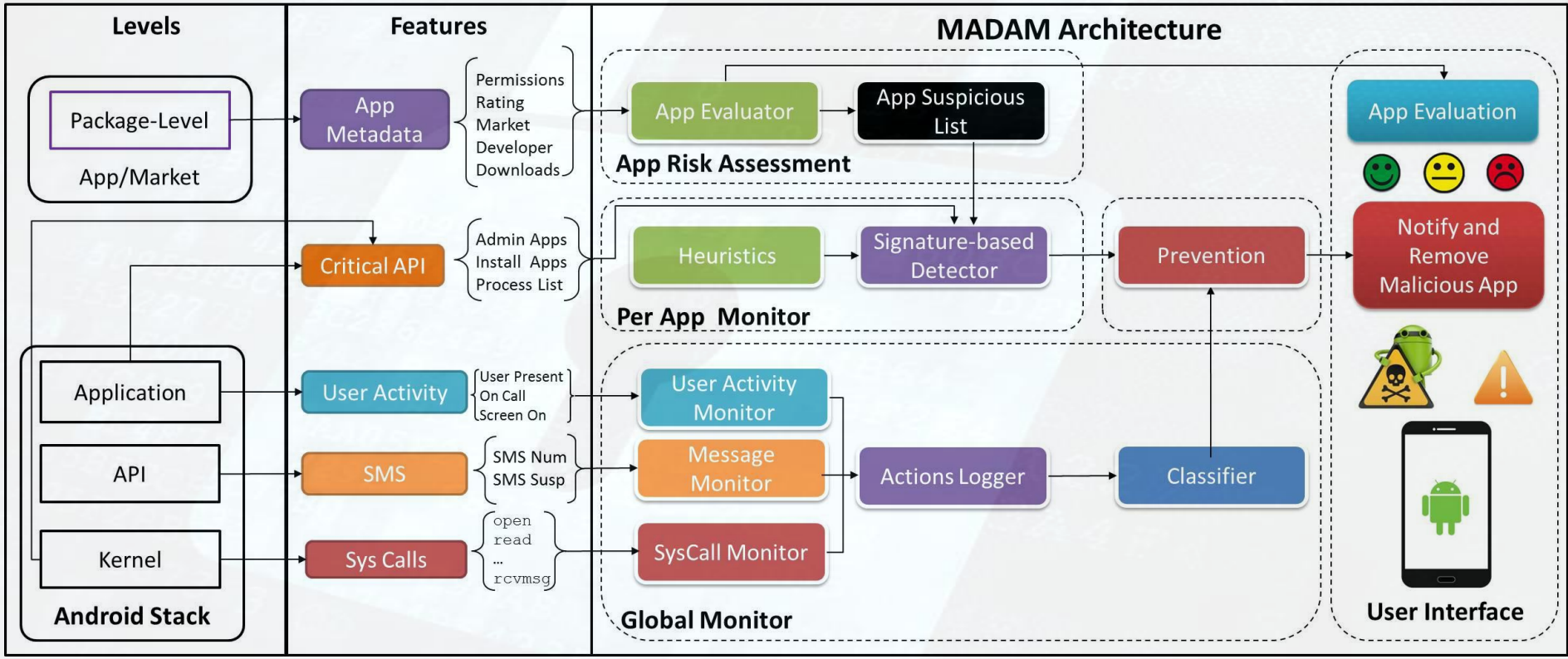
Static Analysis (4)

- Based on the Analytical Hierachy Process (AHP)
  - Weighted sum of scores assigned to the 5 parameters
- Simultaneously analyzes all the parameters and returns a decision:
  - Trusted
  - Untrusted

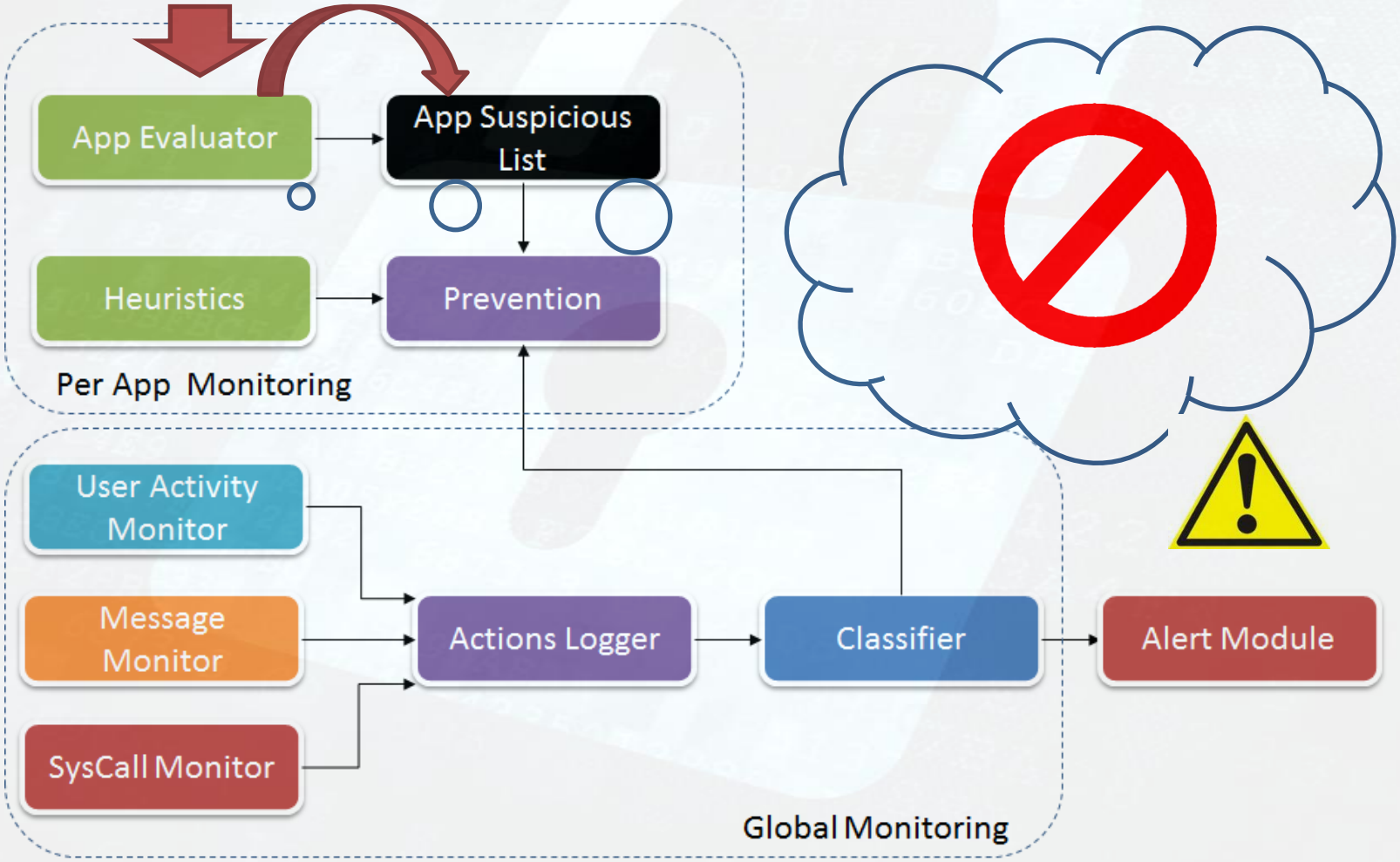
MADAM Workflow



Madam Architecture



MADAM Workflow



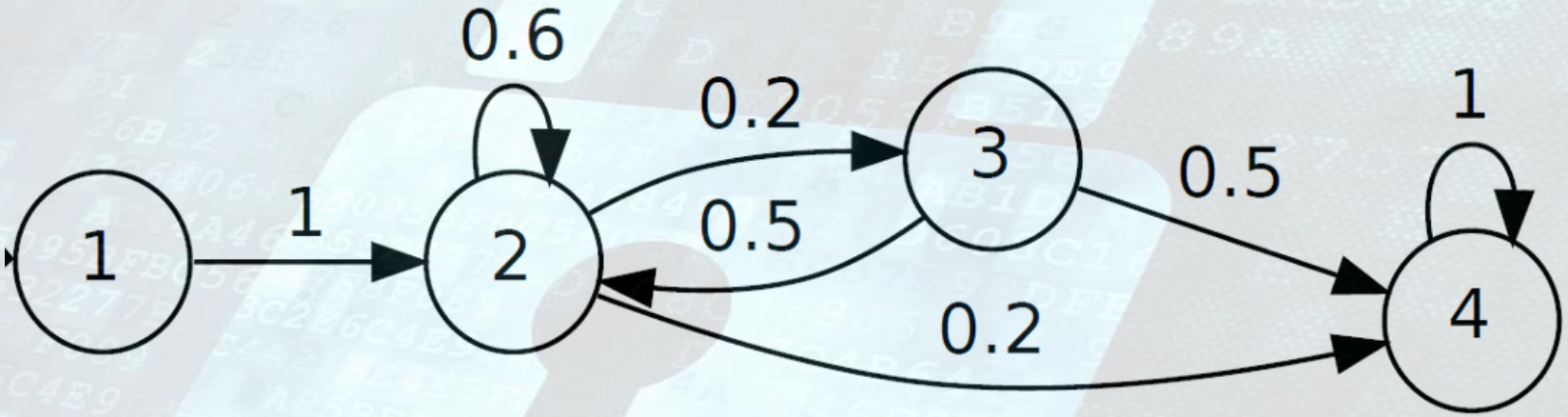
Policies

- Potentially malicious action evaluated against custom security policies.
- Security Policies can be:
  - Manually selected (security policies)
  - Inferred from classifiers (conditions on system calls).
  - Based on specifical behavioral probabilistic patterns expressed through *probabilistic automata* or *logic formula*.

Policies (2)

- Examples:
  - **More than 5k *reads* when user non active -> misbehavior.**
  - **SMS sent to number not in contacts -> misbehavior**
  - **App behavior deviates from expected one -> misbehavior**
  - **App behavior does not match policy specification -> misbehavior**

Policies (3)



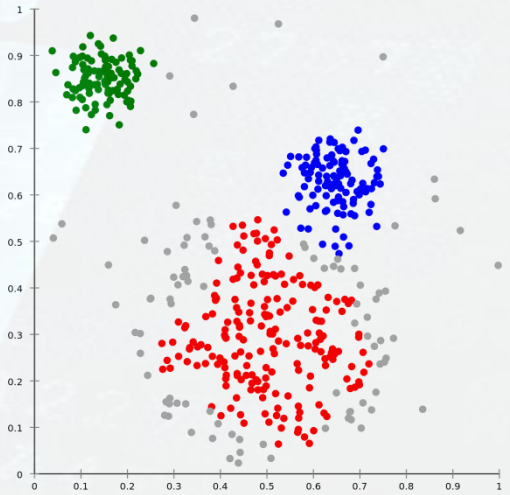
- Probabilistic graph from execution logs to describe expected behavior.
- Markov Chain representation.
- Runtime behavior reconstruction and matching.

Prevention

- If an action violates a policy, it is blocked.
- User is notified of the violation if performed by a suspicious-listed activity.
- Active policies can be set by the user at any time.

Global Monitor

- Classification done through a K-NN classifier with k=1 (1-NN).
- Based on numerical features
  - Issued SysCalls
  - Sent Messages
  - Seconds of user activity
- Good behavior and Bad behaviors form different clusters.



Global Monitor (2)

- Comparison between 2 behaviors (vectors)
  - User Idle (top) VS User Active (bottom)

open	ioctl	brk	read	write	exit	close	sendto	sendmsg	recvfrom	recvmsg	Idleness	SMS Num	SMS Susp
6	19	18	1	4	0	7	16	2	2	0	0	0	0
147	652	192	711	4	282	229	7	15	7	13	1	0	0

- Classification performed through vectors similarity

$$Similarity(x, y) = -\sqrt{\sum_{i=1}^{m}(x_i - y_i)^2}$$

Detection Result (Statistics)

- Training Set: 30000 behavior vectors.
- Malicious Vectors: 800
  - Real malware + Artificially generated (SMOTE)
- TPR = 100%
- FPR = 0,01%

Malware Detection Results

- Three tested datasets of malicious apps:
  - Genome (2012), Contagio (2015), Drebin (2014)
  - Total number of tested apps: 2784
  - Number of families: 123
- Global Accuracy: 99,7%
- 100% accuracy against, SMS Trojan, Installer, Ransomware, Rootkit and general trojan.
- Able to detect the *Android.Poder* trojan, still undetected by most AV.

Discussion

- Malware perform malicious action demanding OS or other components to effectively do the misbehavior.
  - Difficult to find anomalies in syscall issued by apps.
  - Easy to find globally.
  - Static and dynamic approaches are complementary.
- Detection Results compared with *VirusTotal.*
  - Better accuracy (99,7% (MADAM) vs 98% (VT))

Detailed Results

Malware Type	Families	Samples	Static		Dynamic		MADAM	VirusTotal
			Fam	Sam	Fam	Sam		
Botnet	2	7	1	2	0	0	2	7
Installer	6	406	3	236	6	406	406	400
Ransomware	3	30	2	11	3	30	30	30
Rootkit	13	543	10	436	13	543	543	541
SMS Trojan	41	1309	34	785	41	1309	1309	1290
Spyware	38	231	38	231	21	161	231	220
Trojan	5	23	5	20	2	19	20	22
Hybrid	14	243	10	189	14	243	243	243
Composition	1	2	0	0	2	2	2	0
Total	123	2794	103	1910	102	2713	2784	2753
Accuracy							99.7%	98%

Performance

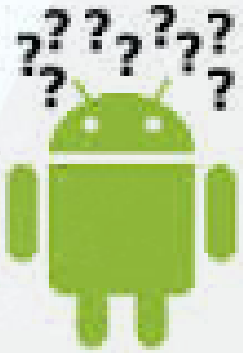
- Testbed:
  - LG Nexus 4
- Overhead (Quadrant tool):
  - Global 1,4%
  - CPU: 0,9%
  - Memory: 9,4%
  - Video 0%
  - Battery: 3%

False Positive Analysis

- On a set of *9804* genuine apps the *0,2%* has been considered suspicious by the *static analysis module*.
- At runtime:
  - Results extracted as average of one week of experiments on three devices with different users.
  - the average amount of FP per day is of 1 (*FPR 1*10^-5*).

Requirements

- Non custom operative device.
- Necessary to have the device rooted (jailbreak).
  - Activate the kernel module.
  - Intercept events and stopping them.



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Future Works

- Increasing the number of policies, their extraction methods and evaluation strategies.
- Using collaborative approaches for intrusion detection
- Using privacy aware techniques for IDS

Thank You

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Related Work

- ***Copperdroid***: performs malware stimulation to discover hidden behavior.
  - Considers actions at Java and JNI level.
  - VM and System call – based.
  - Runs offline (not on device).
- ***TaintDroid:*** analyzes information flows to detect and stops privacy leakage.
  - Allows the definition of security policies for data protection.
  - Requires OS modifications.
  - Attack Specific

Related Work (2)

- ***Alterdroid***: Framework for analysis of Android application to detect faults in static resources.
  - Effective in detecting repackaged apps.
  - Attack specific.
- ***Aurasium***: Framework for enforcement of app specific security policies.
  - Does not consider global features and can be evaded.

Related Work (3)

- ***MOSSDroid:*** static analysis framework for Android malware.
  - Signature based detection.
  - Evaded by zero day threats.
- ***Drebin:*** framework for static analysis and classification of Android malware.
  - Analyzed a large amount of samples.
  - Offline analysis.
  - Drebin DB analyzed by MADAM.

Probabilistic Contract Based Security

- Verifying if app behavior matches security policies.
- Probabilistic security policies:
  - Greater flexibility
  - Smaller fall-out (FPR)
- Generation of probabilistic contract from app execution (sandbox).
- Learning user probabilistic behavior.