US008806647B1

(12) **United States Patent**
Daswani et al.

(10) **Patent No.: US 8,806,647 B1**
(45) **Date of Patent: Aug. 12, 2014**

(54) **BEHAVIORAL SCANNING OF MOBILE APPLICATIONS**

(75) Inventors: **Neilkumar Daswani**, San Jose, CA (US); **Ameet Ranadive**, Fremont, CA (US); **Shariq Rizvi**, Fremont, CA (US); **Michael Gagnon**, Mountain View, CA (US); **Tufan Demir**, Santa Clara, CA (US); **Gerry Eisenhaur**, Emeryville, CA (US)

(73) Assignee: **Twitter, Inc.**, San Francisco, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **13/458,982**

(22) Filed: **Apr. 27, 2012**

Related U.S. Application Data

(60) Provisional application No. 61/478,841, filed on Apr. 27, 2011.

(51) **Int. Cl.**

G06F 12/14	(2006.01)
H04L 29/06	(2006.01)
H04L 9/32	(2006.01)
G06F 21/57	(2013.01)

(52) **U.S. Cl.**
CPC ***G06F 21/577*** (2013.01); ***H04L 63/1433*** (2013.01)
USPC **726/25**; 713/161; 713/165; 713/168; 713/187; 713/188

(58) **Field of Classification Search**
CPC G06F 21/577; H04L 63/1433
USPC 726/25; 713/161, 165, 168, 187, 188
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,664,626	B1 *	2/2010	Ferrie	703/23
8,443,439	B2 *	5/2013	Lamastra et al.	726/22
8,499,353	B2 *	7/2013	Lockhart et al.	726/25
8,510,838	B1 *	8/2013	Sun et al.	726/24
2009/0144823	A1 *	6/2009	Lamastra et al.	726/22
2010/0333088	A1 *	12/2010	Rogel et al.	718/1
2012/0102087	A1 *	4/2012	Chor	709/202
2013/0091570	A1 *	4/2013	McCorkendale et al.	726/23

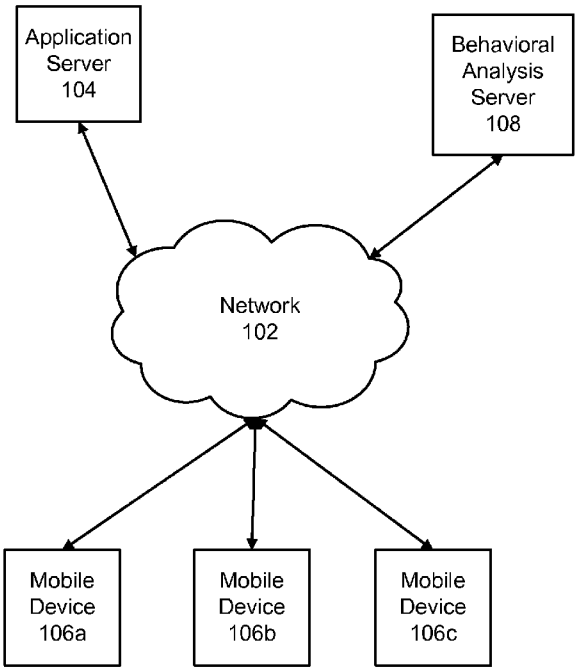
* cited by examiner

Primary Examiner — Aravind Moorthy
(74) *Attorney, Agent, or Firm* — Fenwick & West LLP

(57) **ABSTRACT**

Behavioral analysis of a mobile application is performed to determine whether the application is malicious. During analysis, various user interactions are simulated in an emulated environment to activate many possible resulting behaviors of an application. The behaviors are classified as hard or soft signals. A probability of the application being malicious is determined through combining soft signals, and the application is classified as malicious or non-malicious. Users of the application, the developer of the application, or a distributor of the application are notified of the application classification to enable responsive action.

20 Claims, 6 Drawing Sheets



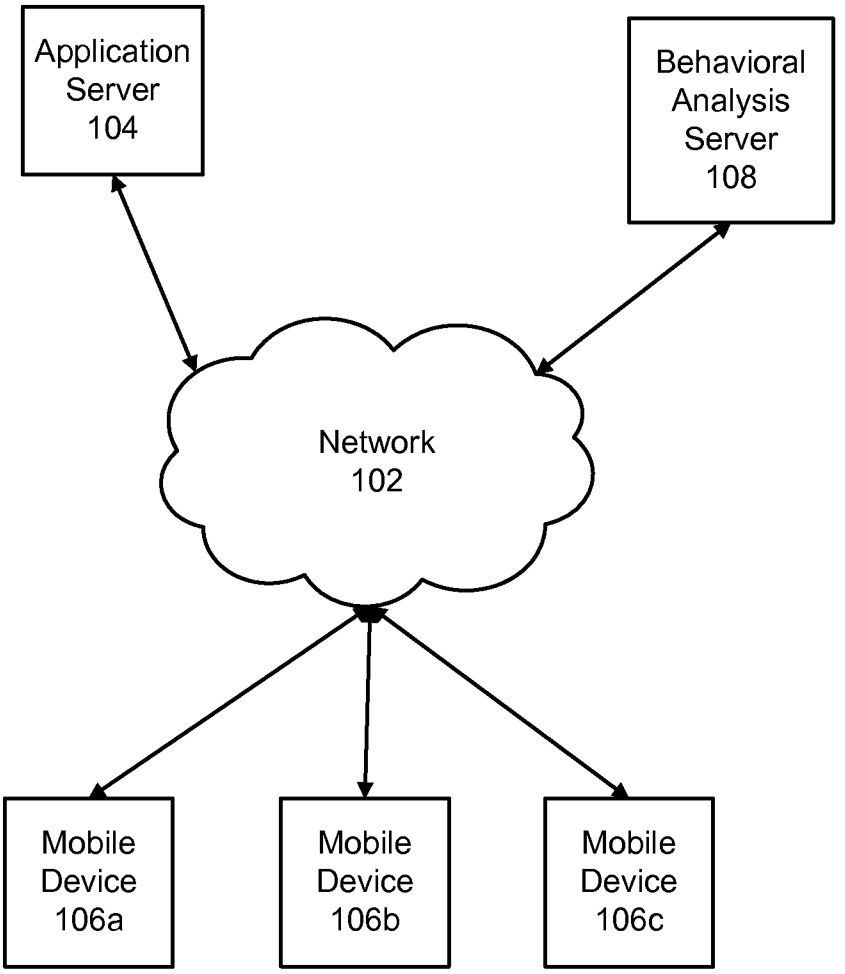

Application Server 104
Behavioral Analysis Server 108
Network 102
Mobile Device 106a
Mobile Device 106b
Mobile Device 106c

FIG. 1

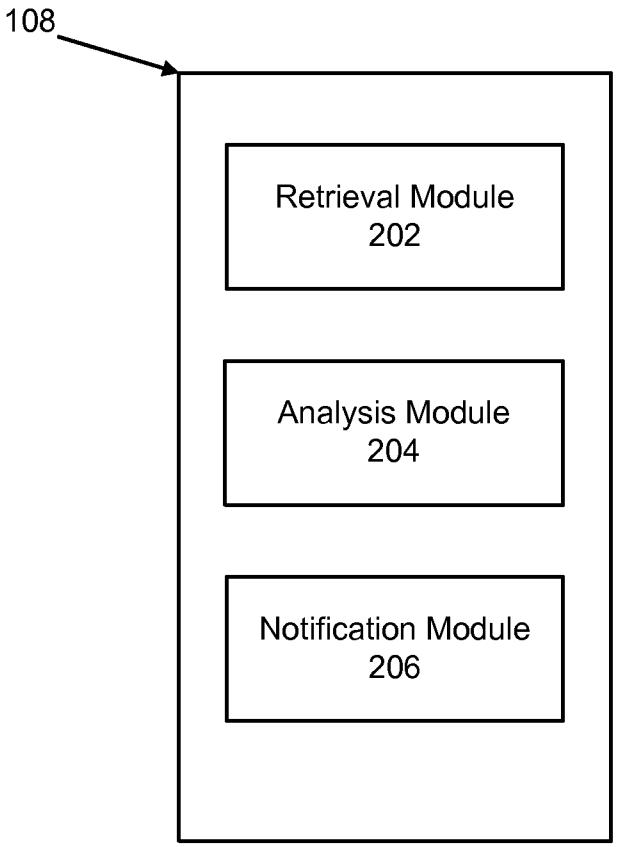

108
Retrieval Module
202
Analysis Module
204
Notification Module
206

FIG. 2

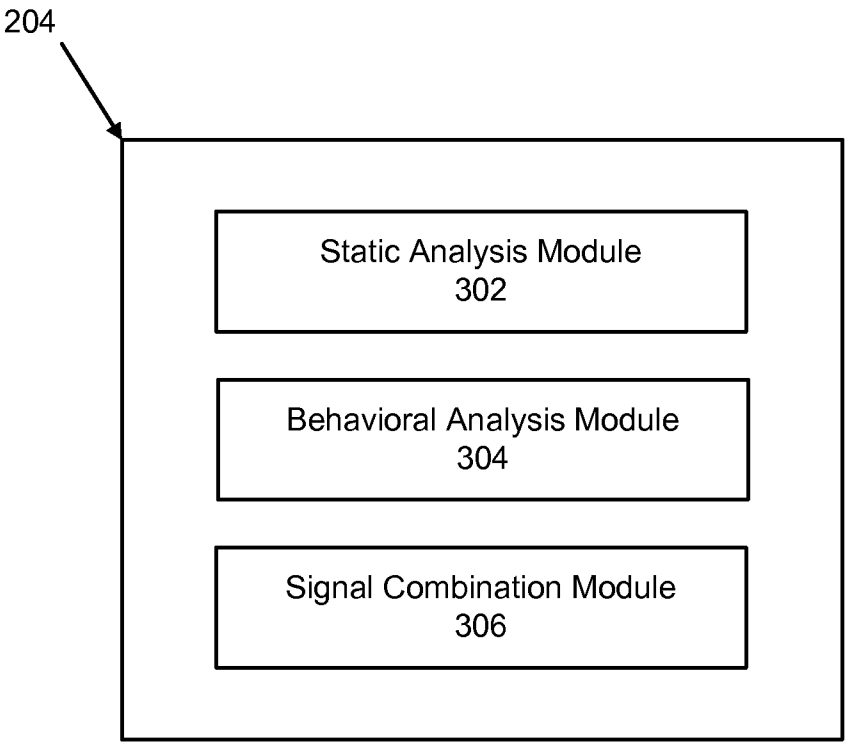

204
Static Analysis Module
302
Behavioral Analysis Module
304
Signal Combination Module
306

FIG. 3

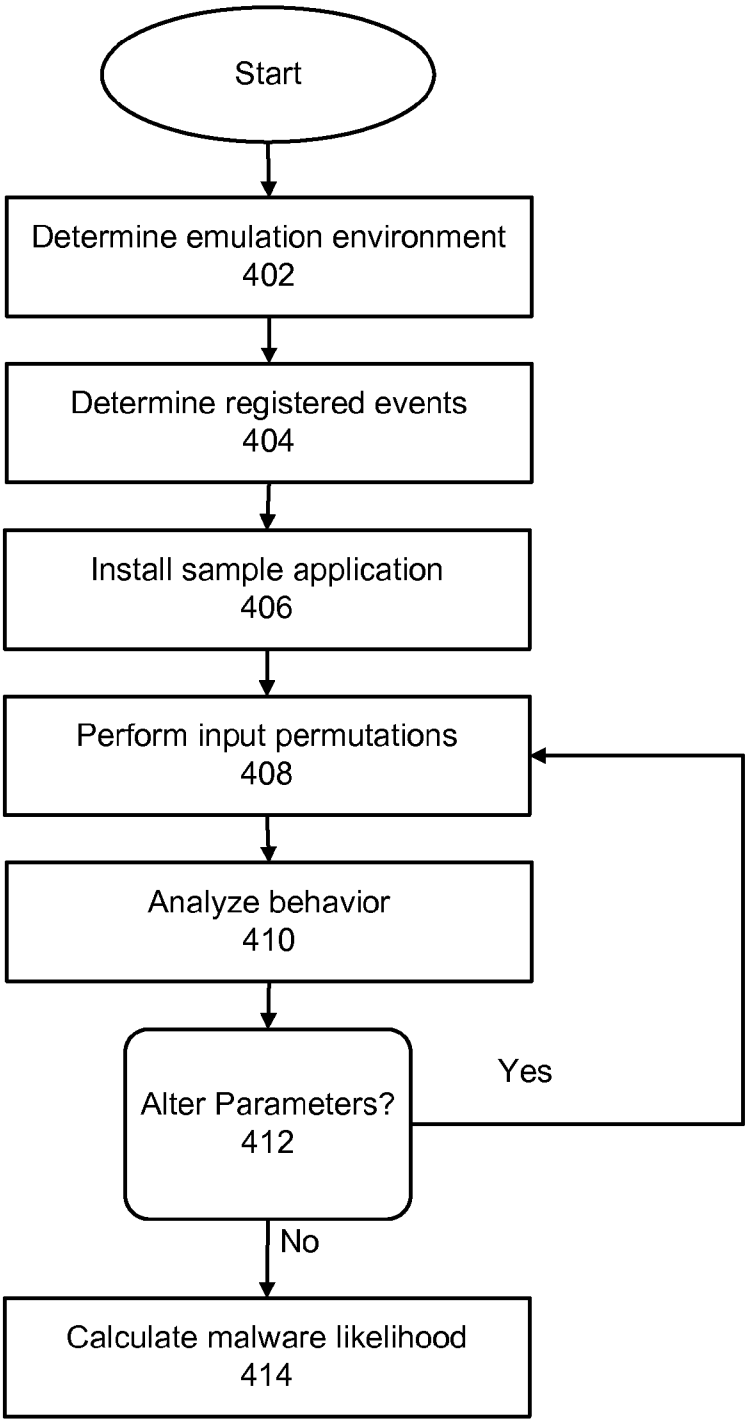

Start
Determine emulation environment
402
Determine registered events
404
Install sample application
406
Perform input permutations
408
Analyze behavior
410
Alter Parameters?
412
Yes
No
Calculate malware likelihood
414

FIG. 4

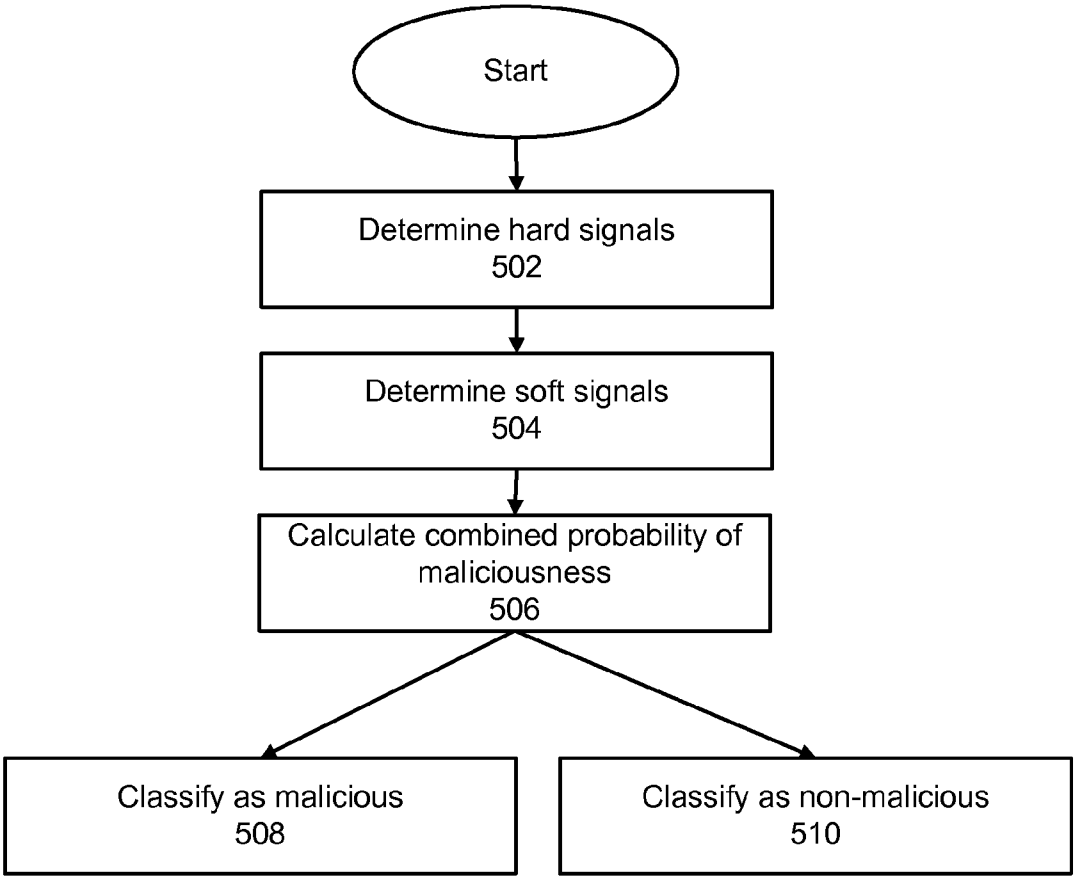

Start
Determine hard signals
502
Determine soft signals
504
Calculate combined probability of maliciousness
506
Classify as malicious
508
Classify as non-malicious
510

FIG. 5

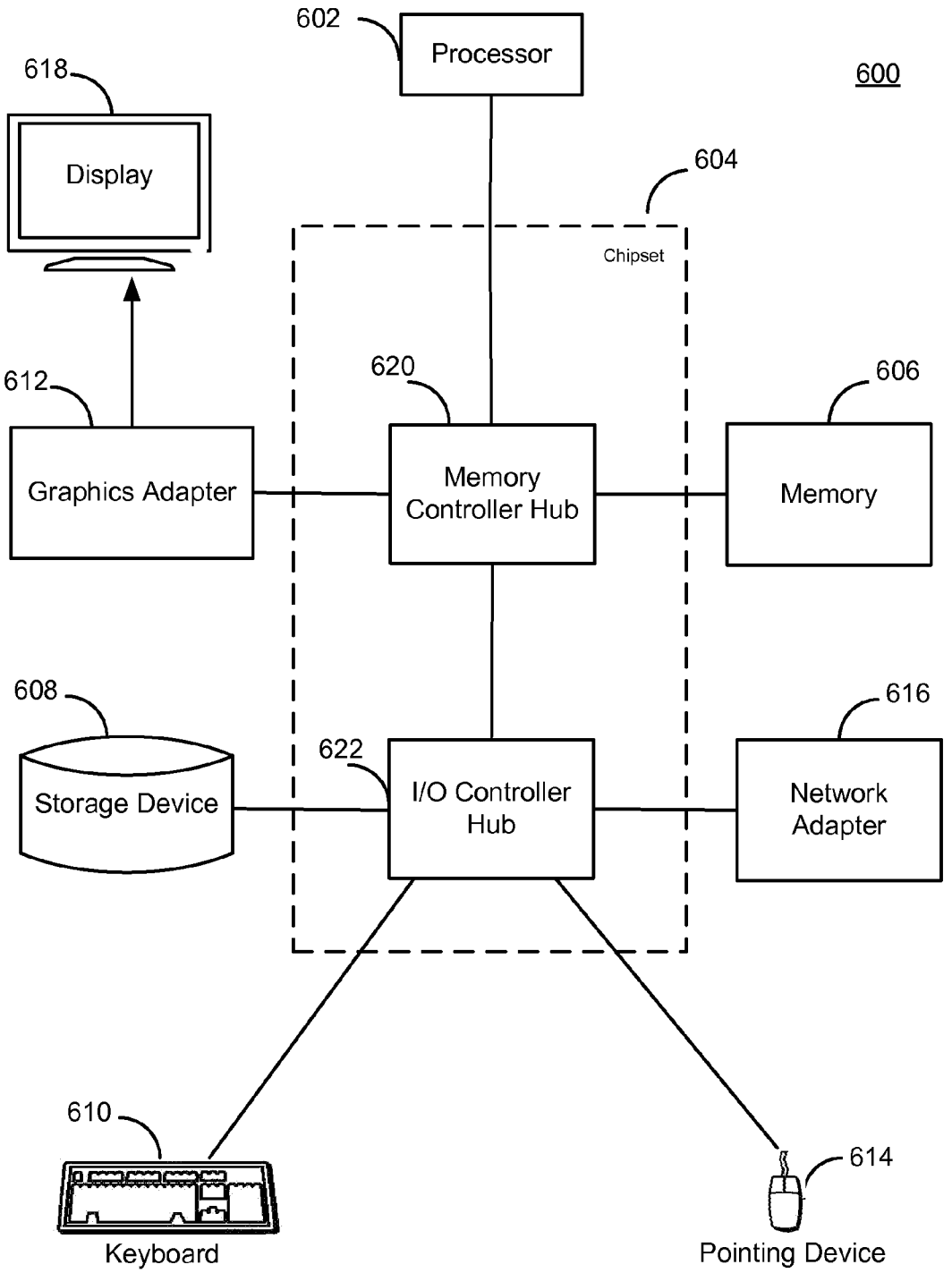

602
Processor
600
618
Display
604
Chipset
620
606
612
Graphics Adapter
Memory Controller Hub
Memory
608
616
622
Storage Device
I/O Controller Hub
Network Adapter
610
614
Keyboard
Pointing Device

Fig. 6

BEHAVIORAL SCANNING OF MOBILE APPLICATIONS

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Application No. 61/479,841, filed Apr. 27, 2011, the contents of which is hereby incorporated by reference in its entirety.

BACKGROUND

1. Field of Disclosure

The disclosure generally relates to the field of malware detection, in particular to detecting malware in computing applications.

2. Description of the Related Art

Malware detection is commonly accomplished by looking for certain signatures within binaries. However, this method of detection can be negated by a malware generator generating variants of a piece of malware. These variants can be scanned with known antivirus engines to ensure that no malware signature match is made. Unmatched variants of malware can then be released into the wild through applications and infect mobile devices. In one example, an attacker might download an application free from malware from an application distribution server. The attacker injects the application with malware and makes the application with injected malware available on the application distribution server.

BRIEF DESCRIPTION OF DRAWINGS

The disclosed embodiments have advantages and features which will be more readily apparent from the detailed description, the appended claims, and the accompanying figures (or drawings). A brief introduction of the figures is below.

FIG. **1** is a block diagram illustrating a computing environment for behavioral analysis of application according to one embodiment of the present disclosure.

FIG. **2** is a block diagram illustrating a behavioral analysis server according to one embodiment of the present disclosure.

FIG. **3** is a block diagram illustrating an analysis module according to one embodiment of the present disclosure.

FIG. **4** is a flow diagram illustrating a method for performing malware detection analysis according to one embodiment of the present disclosure.

FIG. **5** is a flow diagram illustrating a method for combining hard and soft signals to determine a likelihood of malware according to one embodiment of the present disclosure.

FIG. **6** is a block diagram illustrating an example of a computer for use in the computing environment shown in FIG. **1** according to one embodiment of the present disclosure.

DETAILED DESCRIPTION

The computing environment described herein enables behavioral scanning of mobile applications for malware. The Figures (FIGS.) and the following description describe certain embodiments by way of illustration only. One skilled in the art will readily recognize from the following description that alternative embodiments of the structures and methods illustrated herein may be employed without departing from the principles described herein. Reference will now be made in detail to several embodiments, examples of which are illustrated in the accompanying figures. It is noted that wherever practicable similar or like reference numbers may be used in the figures and may indicate similar or like functionality.

The features and advantages described in the specification are not all inclusive and, in particular, many additional features and advantages will be apparent to one of ordinary skill in the art in view of the drawings, specification, and claims. Moreover, it should be noted that the language used in the specification has been principally selected for readability and instructional purposes, and may not have been selected to delineate or circumscribe the disclosed subject matter.

Configuration Overview

Configurations as disclosed allow for malware detection in computing environments, for example, mobile devices (or mobile computing devices). Mobile devices, as further disclosed herein, include smartphones and tablet computers that can be configured to download and install applications (referred to as "apps") from an application store that is online or otherwise on the web. In one embodiment, the disclosed configurations detect uses non-behavioral malware detection systems and techniques to analyze and detect whether installation of a particular application would introduce malware on the mobile computing device.

As disclosed herein, instead of, or in addition to, non-behavioral malware detection, behavioral detection also can be performed to observe the actions of an application and the device on which the application is running. In one example embodiment, the behavioral detection is performed on a software emulation platform. In this configuration, the system is structured to customize the emulated environment, record the observed output, analyze the practical significance of the observed output, and optionally provide suggested course of action, e.g., avoid download, articulate impact on mobile device, etc. For example, through the disclosed configuration, the analyzed output may indicate that download and installation of a particular application would cause a particular impact on mobile device resources, for example, increased processor utilization, increased memory utilization, or increased communication radio utilization, and/or corresponding impact such as decreased battery life.

In one embodiment, mobile applications are examined as part of their submission to an application marketplace, e.g., an online marketplace, prior to the application being made available to end users. This may be done at the request of the marketplace owner, application developer, or a mobile phone carrier. The application is examined to determine whether it exhibits behavioral traits that may be indicative of maliciousness or other behavior that may negatively impact operation of a computing device. Applications may also be tested periodically to detect malicious behavior that activates after a certain number of uses, after a certain date, or in any other conditions that change over time. In one embodiment, behavioral analysis is performed, or more likely to be performed, on applications that are popular, recently uploaded, recently updated, uploaded by an entity without a history of malware free software, or other appropriate criteria.

During scanning, various user interactions are simulated to activate many possible behaviors of an application when it is running on a computing device. Scanning may be performed for different amounts of time both to allow a greater amount of simulated user interactions and to activate behaviors that may occur only after the mobile device running the application has been asleep, the screen has been dimmed, or any other temporally affected behavior has occurred.

System Environment

Referring to FIG. **1**, the computing environment for behavioral analysis of applications comprises one or more application servers **104**, mobile devices (or mobile computing devices) **106***a-c*, behavioral analysis servers **108**, and a network **102**. An example computing device architecture suitable for the various components in the computing environment of FIG. **1** is further described with respect to FIG. **6**. It is noted that the network **102** may be, for example, in the Internet, and can be accessed through wired or wireless connection.

Each of the mobile devices **106***a-c* (collectively referred to as "mobile device **106**") is a computing device with a processor and a memory, e.g., as further described with FIG. **6**, that provides users with an interface to receive and interact with content. Examples of clients **106** include a smartphone, netbook, a laptop or tablet. For ease of discussion and understanding, the configurations herein will be described in the context of mobile device **106**, although it is noted that the principles described herein with respect to the mobile device **106** can also be applied to larger computing system such as a desktop computer or server computer.

Mobile device **106** typically includes an operating system, for example the ANDROID operating system by GOOGLE INC. of Mountain View, Calif., WINDOWS PHONE by MICROSOFT CORPORATION of Redmond, Wash., BLACKBERRY OS by RESEARCH IN MOTION LIMITED of Waterloo, Ontario, Canada, KINDLE FIRE by AMAZON, INC. of Seattle, Wash., or iOS by APPLE INC. of Cupertino, Calif. Mobile device **106** is configured to run various applications which may be downloaded over the network **102**. The applications may or may not contain malware causing nefarious actions to be performed on the mobile device **106**. In one embodiment, applications may be downloaded by the mobile device **106** from the application server **104** over the network **102**.

The application server **104** is a computing device configured to distribute applications to one or more mobile devices. An example computing device is described with respect to FIG. **6**. For example, the application server **104** may be an application store such as GOOGLE PLAY also by GOOGLE INC., the APP STORE by APPLE INC., BLACKBERRY APP WORLD by RESEARCH IN MOTION, or APPSTORE FOR ANDROID by AMAZON INC. In one embodiment, the application server **104** receives an application over the network **102** and makes the application available for distribution to the mobile device **106**. The application server **104** is configured so that it may be notified that an application is malicious. When notified, the application server **104** may perform various remedial actions, for example, removing the application from availability on the app store site, erasing (or requesting authorization to erase) the infected device of a user who has downloaded the application, deleting or disabling the application from the infected device of the user, or quarantining the infected device from the network **102**. Such a quarantine may be complete, or involve a reduction in services until the issue is rectified.

The behavioral analysis server **108** is a computing device configured to analyze applications for malware. In one embodiment, the behavioral analysis server **108** receives an application from the application server **104** prior to the application server **104** making the application available to the mobile device **106**. Alternatively, applications may be analyzed after distribution to the mobile device **106** has occurred. In one embodiment, an application is installed and run on software emulating the operating system of the mobile device **106**. Various input permutations are tested to analyze the resulting behavior of the application. The resulting behavior may include signals indicating the application is likely to contain malware. In one embodiment, soft signal and hard signal classifications are assigned to behaviors to indicate a likelihood that a certain behavior is due to malware on the application being tested. Additionally, in one embodiment, detected soft signals and hard signals can be combined to determine an overall likelihood of the tested application containing malware.

Upon reading this disclosure, one of ordinary skill in the art will understand that the description above includes three mobile devices **106***a-c*, one application server **104** and one behavioral analysis server **108** for the purposes of illustration. In other embodiments, any number of each of these components may be included in the computing environment illustrated by FIG. **1**

Behavioral Analysis Server Configuration

FIG. **2** is a block diagram illustrating the behavioral analysis server **108** according to one example embodiment of the present disclosure. The behavioral analysis server **108** comprises a retrieval module **202**, an analysis module **204** and a notification module **206**.

The retrieval module **202** receives applications from the application server **104** to allow the behavioral analysis server **108** to analyze an application for malware. In one embodiment, an application is automatically retrieved by the retrieval module **202** by scanning applications available from the application server **104** for applications that have not yet been analyzed by the behavioral analysis server **108** and downloading those applications. Applications may also be transmitted to one or more mobile devices **106** prior to analysis by the behavioral analysis server **108**. If an application is found to be malicious after it has been downloaded to a mobile device **106**, the behavioral analysis server **108** may disable the application on the mobile device **106**, provide notification to the user of the mobile device **106**, or take other appropriate action. In one embodiment, an application is sent to the behavioral analysis server **108** by the application server **104** in response to a mobile device **106** downloading the application. In another embodiment, the application server **104** is configured to transmit an application to the behavioral analysis module **108** for analysis before making the application available to the mobile device **106**.

The analysis module **204** performs behavioral analysis on an application retrieved by the retrieval module **202**. In one embodiment, both static and behavioral analyses are performed by the analysis module **204** to properly assess whether an application contains malware. The application is run in an emulated software platform, and a wide range of input permutations are performed in order to monitor the resulting behavior of the application. An emulator can be built from a stock mobile device emulator, and modified to form a mobile sandbox. The sandbox provides an emulated environment corresponding to a device and is suitable for testing an app without installing on the particular device. The sandbox includes hooks for key application programming interfaces (APIs) that a mobile application might communicate through, e.g., calls sent or received. Examples of APIs include those that are used to access a file system, access contacts in an address book, interface with an SMS text subsystem, a interface with a wireless fidelity (WiFi) system, interface with a telephony system, or enable or disable a camera. In one embodiment, the sandbox is also configured to observe an application's network behavior, graphical user interface and other aspects for black-box monitoring, in addition to white-box monitoring of API calls.

In one embodiment, the sandbox uses an event generator or user interface exerciser that generates events such as touch

screen interaction, microphone and speaker volume level button pressing, ringer volume or vibration button pressing, and any other possible user interaction. The event generator looks at the manifest for an application and looks at what event handlers it processes to determine which actions should be simulated in behavioral analysis. Behaviors may be classified as unsuspicious, soft signals, or hard signals. In one embodiment, these classifications are assigned based on a behavior's likelihood of being performed due to malware in the application. Additionally, multiple classified behaviors may be combined to determine an overall risk or likelihood of malware being present in the application. The analysis module **204** is discussed in more detail in FIG. **3**.

The notification module **206** is configured to take action based on the results of the analysis module **204**. For example, if an application is determined to likely contain malware, the application server **104**, or an administrator of the application server **104**, may be notified of the malware. Additionally, the notification module **206** may notify mobile devices that an application has been found to contain malware. In one embodiment, the notification may be limited to those mobile devices that have installed the infected application. The notification may also include instructions on how to eliminate or reduce the threat posed by the newly detected malware.

Turning now to FIG. **3**, the analysis module **204** is further described. The analysis module **204** comprises a static analysis module **302**, a behavioral analysis module **304** and a signal combination module **306**.

The static analysis module **302** performs a static analysis on a sample of an application to enable full behavioral analysis of the application. In one embodiment, the manifest of the application is analyzed to determine all events which the application registers for when it will be executing. Events correspond to objects sent to an application to inform it of user or system actions. The events may include multitouch events, accelerometer or GPS events, remote control events or other inputs triggered through user action or system hardware. In one embodiment, an application may request permission to utilize certain events during runtime. These requested event types can then be targeted during the input simulation portion of behavioral analysis. In certain operating systems, an application registers for actions which the application can be granted access to. By determining all of these events, the behavioral analysis module **304** can attempt to place an emulated mobile device in various states through simulated user interactions. The states include an unsuspicious state or one of two levels of suspicious states. With respect to the suspicious states, the behavior analysis module **304** determines what events might cause suspicious actions to be performed by the application and the actions or behaviors can be classified as hard signals or soft signals, which are further described herein.

In addition, the static analysis module **302** determines the emulator environment that should be used to properly test the behavior of an application. In one embodiment, the emulator environment is controlled for operating system and operating system version of the mobile device, other applications installed, and hardware features or revisions. The emulator environment can retrieve and store multiple versions (and if applicable, release or revision level) of operating systems and mobile applications to ensure that a wide variety of platform configurations can be simulated during behavioral testing. Certain applications, or versions of operating systems or applications may need to be installed for an application to exhibit behavior that may be classified as a hard or soft signal and therefore indicative of malware being present. Determining which versions of software should be installed can be performed through static analysis of the application being tested, random testing, or through notification from those who have experienced malicious behavior. In one embodiment, the emulated environment includes seed information such as contacts in an address book, seeded global positioning system (GPS) locations, internet history, and other information better simulating an actual user's device. This better enables to the emulator to make an application exhibit a wide range of behaviors during behavioral analysis.

Behavioral analysis module **304** performs a series of steps to recognize hard and soft signals indicative of the application containing malware. An image of the emulated environment determined in static analysis is loaded allowing the application to be tested under proper conditions. A sample of the application is then installed on the emulated environment and the application is started. A user interface exerciser, for example, MONKEY by GOOGLE INC. may be used to generate a stream of events that simulate user input and various system level events. In one embodiment, the stream of inputs or events is generated randomly. Alternatively, the stream of user inputs may be directed to ensure that all application registered events and permissions identified during static analysis are triggered during runtime. Static analysis module **302** determines what events an application accepts from a user. For example, if a username and password are solicited in a dialog box, the user interface exerciser provides a username and password and takes an action through the dialog box to submit (e.g., ok or enter). In one embodiment, a debugging utility, such as STRACE is utilized to monitor system calls made by the application. This enables all system calls, actions, and other behaviors of the application to be stored during behavioral analysis. The observed behaviors may then be analyzed and classified as hard signals or soft signals.

In one embodiment, multiple behavioral analyses are performed in succession, using the results of a previous test to modify the user inputs which are simulated by the user interface exerciser. For example, if a large number of soft signals are observed after accessing a certain portion of the application which receives address book information, another behavioral analysis may be performed with user inputs focused on provoking address book interaction. This may be repeated any number of times to better assess the maliciousness of an application.

Signal combination module **306** combines multiple behaviors signals to determine an overall likelihood that an application is malicious. In one embodiment, some system calls or actions simulated in the emulated environment may be classified as soft signals or hard signals. In one embodiment, soft signals comprise system calls or actions which have an associated probability of the application containing malware. Hard signals comprise system calls or actions that are by definition malicious actions, or associated with a probability of the application containing malware, the probability exceeding a hard signal threshold. For example, a soft signal may be accessing an address book on the mobile device. This action may be used for malicious purposes, but is often benign. In one embodiment, a soft signal has a higher probability of maliciousness if similar applications are unlikely to perform a similar action. A soft signal of accessing address book information may also be assigned an increased probability of maliciousness based on the amount of address book entries accessed or the pattern in which entries are accessed. For example, iteratively retrieving every address from an address book may be assigned a higher probability of maliciousness. On the other hand, contacting an internet protocol (IP) address associated with a known malicious botmaster

may be classified as a hard signal due to the small probability of benign software performing such an action.

In one embodiment, if a hard signal is observed in an application, the application is classified as malicious. This may be due to a probability of malicious content exceeding a predefined threshold or threshold value of what comprises or corresponds with malicious content. Alternately, it may be due to being innate in the action performed by the hard signal.

Likewise if one or more independent soft signals are observed, each of the soft signals has their own probability of indicating that an application is malicious. According to one embodiment, the probability of maliciousness, X, that an application is malicious when a single independent soft signal is observed is shown in equation (1) below, where P is the overall probability that any application contains malware without specific information about the application, D is the detection rate or probability that the soft signal is observed for a malicious application, and F is the false positive rate or probability that the soft signal is observed for a legitimate application.

$$X=(D*P)/(D*P+F*(1-P)) \quad (1)$$

The equation indicates that both the detection rate and false positive rate of observed soft signals are taken into account. A signal with a high detection rate and a low false positive rate increases the probability of maliciousness when the signal is observed. The probability of maliciousness of multiple soft signals may then be taken into account to determine a combined probability of maliciousness. It should be noted that equation 1 and the related discussion is merely an example of probability calculations that may be used if the soft signals are all independent. In one embodiment, the application is identified as malicious if the combined probability of maliciousness exceeds a threshold. In one embodiment, the threshold is the same threshold of probability used to classify an individual signal as a hard signal. Alternatively, the probability of maliciousness threshold for a hard signal may be higher or lower than the combined probability of maliciousness threshold. In one embodiment, soft signals are not independent, but rather their associated probability of maliciousness varies based on other soft signals that are observed in an application.

Referring now to FIG. **4**, a flow diagram illustrates an example method for performing application malware analysis according to one embodiment of the present disclosure. After receiving an application sample for analysis, the analysis module **204** determines **402** the emulation environment in which the application should be tested. The manifest of the application is also analyzed by the analysis module **204** to determine **404** events for which the application is registered. The sample application is then installed **406** on the emulated image of the mobile device conforming to the previously determined emulation environment. Pseudo-random streams of user events such as clicks, touches, gestures, and various system-level events are generated to perform **408** a wide variety of input permutation in the emulated software and the resulting behavior is logged. Analysis module **204** then analysis **410** the recorded behavior to identify behaviors which may be classified as soft signals and hard signals. Based on results, analysis module **204** may decide that the test should be performed again with altered **412** parameters. If this occurs, step **408** is performed once again on the application with a new set of generated user events. Otherwise, analysis module **204** calculates **414** the likelihood of the application sample containing malware based on the soft and hard signals identified in recorded behaviors. The result of analysis may be reported to the application server **104** and/or the mobile device **106** to inform whether an application is malicious and, optionally, the probability that the application is malicious.

FIG. **5** is a flow diagram illustrating an example method for combining hard signals and soft signals to determine a likelihood of malware according to one embodiment of the present disclosure. After the analysis module **204** observes behaviors and classifies hard and soft signals, the analysis module **204** proceeds to assess the likelihood of an application being malicious based on hard and soft signal infection rates and a false positive rate. Analysis module **204** determines **502** observed hard signal behaviors and determines a probability of maliciousness for each of the hard signals. Similarly, analysis module **204** determines **504** observed soft signal behaviors and determines a probability of maliciousness for each of the soft signals. In one embodiment, as previously discussed, individual hard signals have a probability of maliciousness high enough to classify the application as malicious. On the other hand, the probability of maliciousness for each of the observed soft signals is combined to calculate **506** a combined probability of maliciousness. If hard signal is observed, or if the combined probability of maliciousness exceeds a maliciousness threshold, the application is classified **508** as malicious. If no hard signal is observed, and if the combined probability of maliciousness fails to exceed the maliciousness threshold, the application is classified as non-malicious.

Example Computing Architecture

The entities shown in FIGS. **1-5** are implemented using one or more computers. A computer used to implement these entities may take on a variety of form factors. For example, in on embodiment, mobile device **106** is a smartphone configured to run applications downloaded over the network **102**. FIG. **6** is a high-level block diagram illustrating an example computer **600**. The computer **600** includes at least one processor **602** coupled to a chipset **604**. The chipset **604** includes a memory controller hub **620** and an input/output (I/O) controller hub **622**. A memory **606** and a graphics adapter **612** are coupled to the memory controller hub **620**, and a display **618** is coupled to the graphics adapter **612**. A storage device **608**, keyboard **610**, pointing device **614**, and network adapter **616** are coupled to the I/O controller hub **622**. Other embodiments of the computer **600** have different architectures.

The storage device **608** is a non-transitory computer-readable storage medium such as a hard drive, compact disk read-only memory (CD-ROM), DVD, or a solid-state memory device. The memory **606** holds instructions and data used by the processor **602**. The pointing device **614** is a mouse, track ball, or other type of pointing device, and is used in combination with the keyboard **610** to input data into the computer system **600**. The graphics adapter **612** displays images and other information on the display **618**. The network adapter **616** couples the computer system **600** to one or more computer networks.

The computer **600** is adapted to execute computer program modules for providing functionality described herein. As used herein, the term "module" refers to computer program logic used to provide the specified functionality. Thus, a module can be implemented in hardware, firmware, and/or software. In one embodiment, program modules are stored on the storage device **608**, loaded into the memory **606**, and executed by the processor **602**.

The types of computers **600** used by the entities of FIGS. **1-5** can vary depending upon the embodiment and the processing power required by the entity. For example, the behavioral analysis server **108** might comprise multiple blade servers working together to provide the functionality described

herein. The computers **600** can lack some of the components described above, such as keyboards **610**, graphics adapters **612**, and displays **618**.

Additional Considerations

The disclosed configurations beneficially provide behavioral malware detection that can be applied with or without static malware detection to evaluate whether a particular software application is potentially harmful malware when installed on a mobile device. In one example embodiment, the behavioral detection is performed on a software emulation platform. In this configuration, the system is structured to customize the emulated environment, record the observed output, analyze the impact of the observed output, and optionally provide suggested course of action.

In the description above, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the illustrated system and its operations. It will be apparent, however, to one skilled in the art that the system can be operated without these specific details. In other instances, structures and devices are shown in block diagram form in order to avoid obscuring the system.

Reference in the specification to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the system. The appearances of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment.

Some portions of the detailed descriptions, like the processes described in FIGS. **4-5**, are presented in terms of algorithms and symbolic representations of operations on data bits within a computer memory. An algorithm is here, and generally, conceived to be steps leading to a desired result. The steps are those requiring physical transformations or manipulations of physical quantities. Usually, though not necessarily, these quantities take the form of electrical or magnetic signals capable of being stored, transferred, combined, compared, and otherwise manipulated. It has proven convenient at times, principally for reasons of common usage, to refer to these signals as bits, values, elements, symbols, characters, terms, numbers, or the like.

It should be borne in mind, however, that all of these and similar terms are to be associated with the appropriate physical quantities and are merely convenient labels applied to these quantities. Unless specifically stated otherwise as apparent from the following discussion, it is appreciated that throughout the description, discussions utilizing terms such as "processing" or "computing" or "calculating" or "determining" or "displaying" or the like, refer to the action and processes of a computer system, or similar electronic computing device, that manipulates and transforms data represented as physical (electronic) quantities within the computer system's registers and memories into other data similarly represented as physical quantities within the computer system memories or registers or other such information storage, transmission or display devices.

The operations described herein can be performed by an apparatus. This apparatus may be specially constructed for the required purposes, or it may comprise a general-purpose computer selectively activated or reconfigured by a computer program stored in the computer. Such a computer program may be stored in a computer readable storage medium, such as, but is not limited to, any type of disk including floppy disks, optical disks, CD-ROMs, and magnetic-optical disks, read-only memories (ROMs), random access memories (RAMs), EPROMs, EEPROMs, magnetic or optical cards, or any type of media suitable for storing electronic instructions.

The figures and the description above relate to various embodiments by way of illustration only. It should be noted that from the following discussion, alternative embodiments of the structures and methods disclosed herein will be readily recognized as viable alternatives that may be employed without departing from the principles of what is claimed.

One or more embodiments have been described above, examples of which are illustrated in the accompanying figures. It is noted that wherever practicable similar or like reference numbers may be used in the figures and may indicate similar or like functionality. The figures depict embodiments of the disclosed system (or method) for purposes of illustration only. One skilled in the art will readily recognize from the following description that alternative embodiments of the structures and methods illustrated herein may be employed without departing from the principles described herein.

Some embodiments may be described using the expression "coupled" and "connected" along with their derivatives. It should be understood that these terms are not intended as synonyms for each other. For example, some embodiments may be described using the term "connected" to indicate that two or more elements are in direct physical or electrical contact with each other. In another example, some embodiments may be described using the term "coupled" to indicate that two or more elements are in direct physical or electrical contact. The term "coupled," however, may also mean that two or more elements are not in direct physical or electrical contact with each other, but yet still co-operate or interact with each other. The embodiments are not limited in this context.

Also, some embodiments of the system, like the ones described in FIGS. **2-3**, may be further divided into logical modules. One of ordinary skill in the art will recognize that a computer or another machine with instructions to implement the functionality of one or more logical modules is not a general purpose computer. Instead, the machine is adapted to implement the functionality of a particular module. Moreover, the machine embodiment of the system physically transforms the electrons representing various parts of content and data representing user interaction with the content into different content or data representing determined resonance.

As used herein, the terms "comprises," "comprising," "includes," "including," "has," "having" or any other variation thereof, are intended to cover a non-exclusive inclusion. For example, a process, method, article or apparatus that comprises a list of elements is not necessarily limited to only those elements but may include other elements not expressly listed or inherent to such process, method, article or apparatus. Further, unless expressly stated to the contrary, "or" refers to an inclusive or and not to an exclusive or. For example, a condition A or B is satisfied by any one of the following: A is true (or present) and B is false (or not present), A is false (or not present) and B is true (or present), and both A and B are true (or present).

In addition, use of the "a" or "an" are employed to describe elements and components of the embodiments herein. This is done merely for convenience and to give a general sense of the system. This description should be read to include one or at least one and the singular also includes the plural unless it is obvious that it is meant otherwise.

Upon reading this disclosure, those of skill in the art will appreciate still additional alternative structural and functional designs for a system and a process for detecting potential malware using behavioral scanning analysis through the disclosed principles herein. Thus, while particular embodiments and applications have been illustrated and described, it is to be

understood that the disclosed embodiments are not limited to the precise construction and components disclosed herein. Various modifications, changes and variations, which will be apparent to those skilled in the art, may be made in the arrangement, operation and details of the method and apparatus disclosed herein without departing from the spirit and scope defined in the appended claims.

What is claimed is:

1. A computer-implemented method for analyzing mobile applications for malware, the method comprising:

receiving a mobile application from an application server;

loading the mobile application into an emulated environment, the emulated environment simulating a mobile device;

performing static analysis on the application to determine a plurality of simulated user inputs;

loading a user interface exerciser configured to simulate the plurality of simulated user inputs in the mobile application and observing resulting behaviors of the simulated mobile device;

classifying the behaviors as hard signals or soft signals and combining soft signals to calculate a probability of maliciousness; and

classifying the mobile application as malicious or non-malicious based on the hard signals and the probability of maliciousness.

2. The method of claim **1**, further comprising:

determining a second plurality of simulated user inputs responsive to observing the resulting behaviors of the simulated mobile device; and

simulating the second plurality of user inputs.

3. A computer-implemented method for analyzing mobile applications for malware, the method comprising:

loading a mobile application into an emulated environment, the emulated environment simulating a mobile device;

determining a plurality of simulated user inputs;

loading a user interface exerciser configured to simulate the plurality of simulated user inputs on the simulated mobile device;

assessing malware probabilities of behaviors on the mobile device resulting from the simulation of the plurality of simulated user inputs; and

preparing a vulnerability report based on the assessed malware probabilities.

4. The method of claim **3**, wherein assessing malware probabilities further comprises classifying behaviors as a hard signal or a soft signal, a hard signal classification resulting in the application being assessed to have malware.

5. The method of claim **4**, wherein multiple behaviors are classified as soft signals and combined to calculate a combined maliciousness probability.

6. The method of claim **3**, further comprising:

scanning an application marketplace for applications on which to perform malware probability assessment; and

retrieving the mobile application from the application marketplace.

7. The method of claim **3**, further comprising:

determining a second plurality of simulated user inputs responsive to assessing malware probabilities of behaviors; and

simulating the second plurality of user inputs.

8. The method of claim **3**, wherein simulating the plurality of simulated user inputs comprises storing the behaviors of the mobile device resulting from the simulation.

9. The method of claim **3**, wherein the emulated environment comprises an emulated mobile operating system and applications installed on the emulated mobile operating system.

10. The method of claim **3**, wherein determining a plurality of simulated user inputs comprises performing static analysis on the application to identify registered application permissions.

11. The method of claim **3**, wherein the vulnerability report indicates a probability of the mobile application containing malware.

12. A computer system for analyzing mobile applications for malware, the system comprising a non-transitory computer readable medium storing instructions for:

loading a mobile application into an emulated environment, the emulated environment simulating a mobile device;

determining a plurality of simulated user inputs;

loading a user interface exerciser configured to simulate the plurality of simulated user inputs on the simulated mobile device;

assessing malware probabilities of behaviors on the mobile device resulting from the simulation of the plurality of simulated user inputs; and

preparing a vulnerability report based on the assessed malware probabilities.

13. The computer system of claim **12**, wherein assessing malware probabilities further comprises classifying behaviors as a hard signal or a soft signal, a hard signal classification resulting in the application being assessed to have malware.

14. The computer system of claim **13**, wherein multiple behaviors are classified as soft signals and combined to calculate a combined maliciousness probability.

15. The computer system of claim **12**, further comprising:

scanning an application marketplace for applications on which to perform malware probability assessment; and

retrieving the mobile application from the application marketplace.

16. The computer system of claim **12**, further comprising:

determining a second plurality of simulated user inputs responsive to assessing malware probabilities of behaviors; and

simulating the second plurality of user inputs.

17. The computer system of claim **12**, wherein simulating the plurality of simulated user inputs comprises storing the behaviors of the mobile device resulting from the simulation.

18. The computer system of claim **12**, wherein the emulated environment comprises an emulated mobile operating system and applications installed on the emulated mobile operating system.

19. The computer system of claim **12**, wherein determining a plurality of simulated user inputs comprises performing static analysis on the application to identify registered application permissions.

20. The computer system of claim **12**, wherein the vulnerability report indicates a probability of the mobile application containing malware.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 8,806,647 B1
APPLICATION NO. : 13/458982
DATED : August 12, 2014
INVENTOR(S) : Neilkumar Daswani et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title page, item (60), line 1: replace provisional application No. "61/478,841" with --61/479,841--.

Signed and Sealed this
Twenty-ninth Day of September, 2015

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office