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(54) **SYSTEMS AND METHODS TO DETERMINE ATTACK PATHS TO APPLICATION ASSETS**

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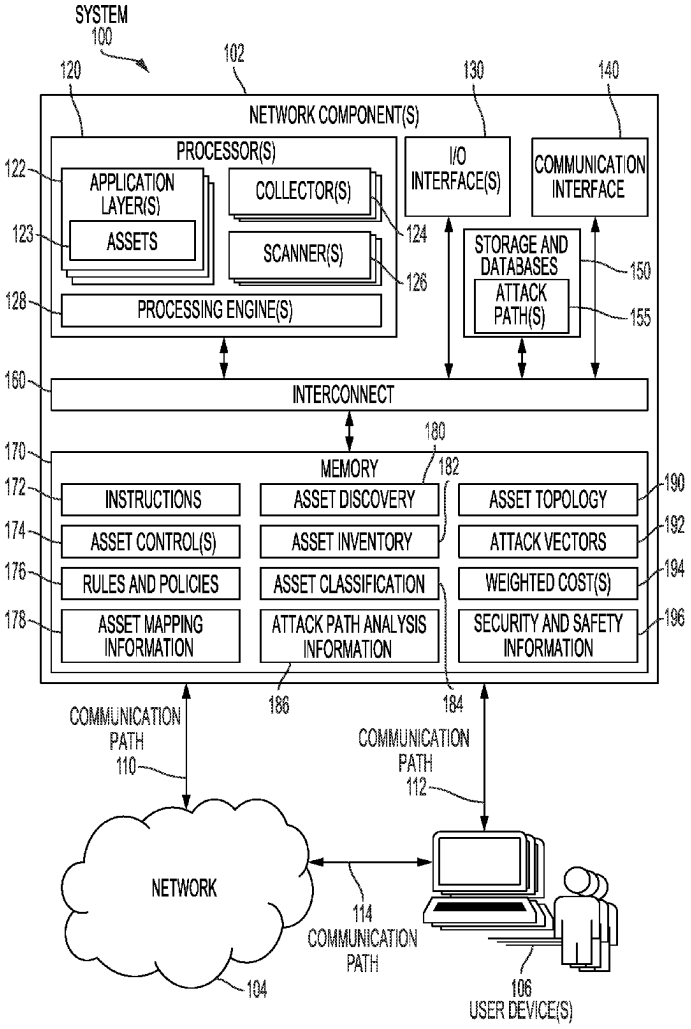
(57) **ABSTRACT**

A system and a method to determine attack paths to application assets may include storing in a memory asset inventory indicating multiple application assets, multiple attack vector parameters configured to indicate vulnerabilities of one or more of the application assets, and asset mapping information configured to associate each of the application assets to one or more of the application layers. A processor may determine multiple vulnerable assets in the application assets based at least in part upon the attack vector parameters. Further, the processor may determine feasibility parameters that indicate a likelihood of the attack path to occur in the system, generate a visual interface showing the vulnerable assets, determine an attack path connecting the vulnerable assets based at least in part upon the asset mapping information, and map the attack path to the application layers in the visual interface based at least in part upon the feasibility parameters.



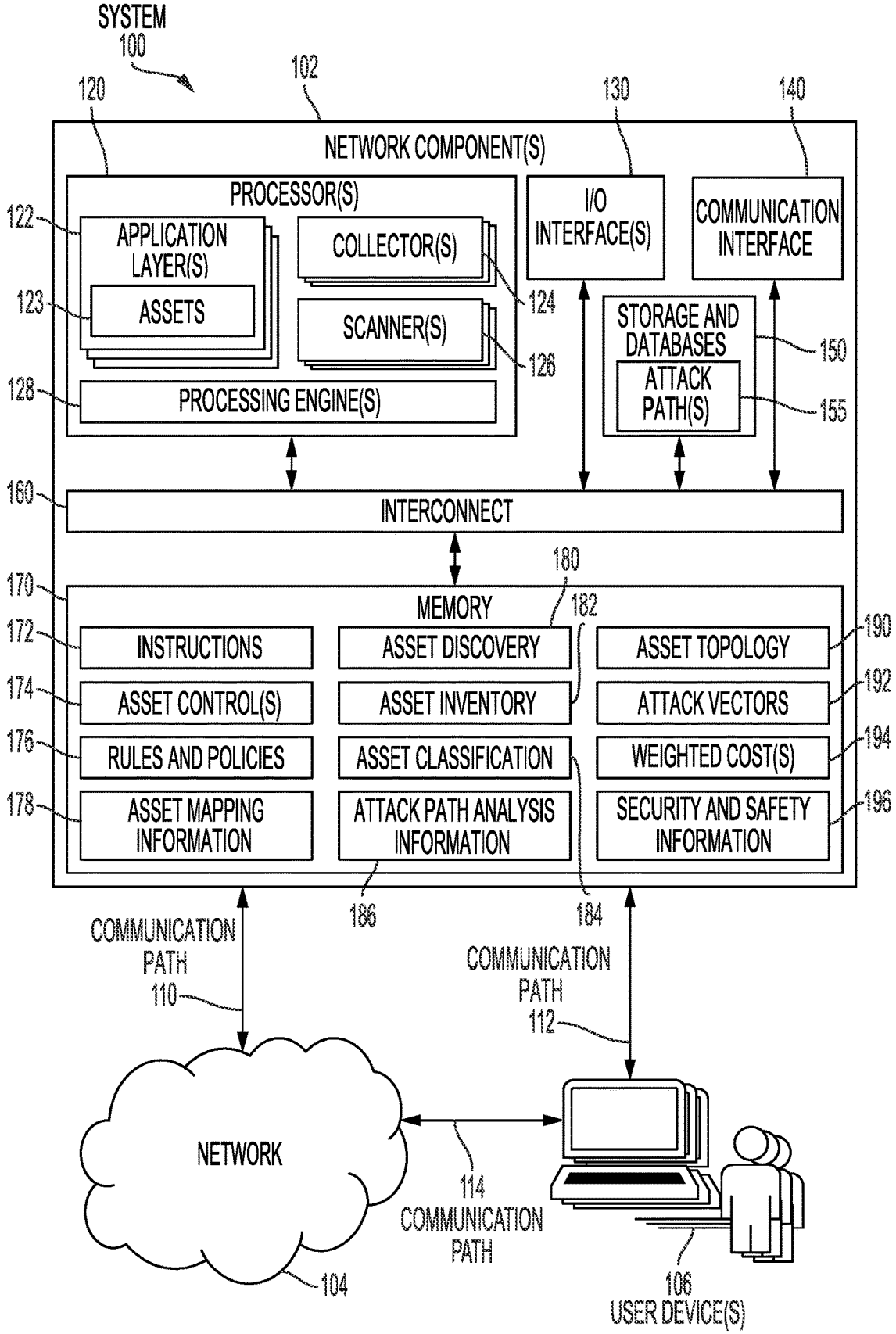

SYSTEM
100
102
120
130
140
NETWORK COMPONENT(S)
PROCESSOR(S)
I/O INTERFACE(S)
COMMUNICATION INTERFACE
122
APPLICATION LAYER(S)
ASSETS
123
COLLECTOR(S)
124
SCANNER(S)
126
STORAGE AND DATABASES
150
ATTACK PATH(S)
155
128
PROCESSING ENGINE(S)
160
INTERCONNECT
180
170
MEMORY
182
172
INSTRUCTIONS
ASSET DISCOVERY
ASSET TOPOLOGY
190
174
ASSET CONTROL(S)
ASSET INVENTORY
ATTACK VECTORS
192
176
RULES AND POLICIES
ASSET CLASSIFICATION
WEIGHTED COST(S)
194
178
ASSET MAPPING INFORMATION
ATTACK PATH ANALYSIS INFORMATION
SECURITY AND SAFETY INFORMATION
196
186
184
COMMUNICATION PATH
110
COMMUNICATION PATH
112
NETWORK
114
COMMUNICATION PATH
104
106
USER DEVICE(S)

FIG. 1

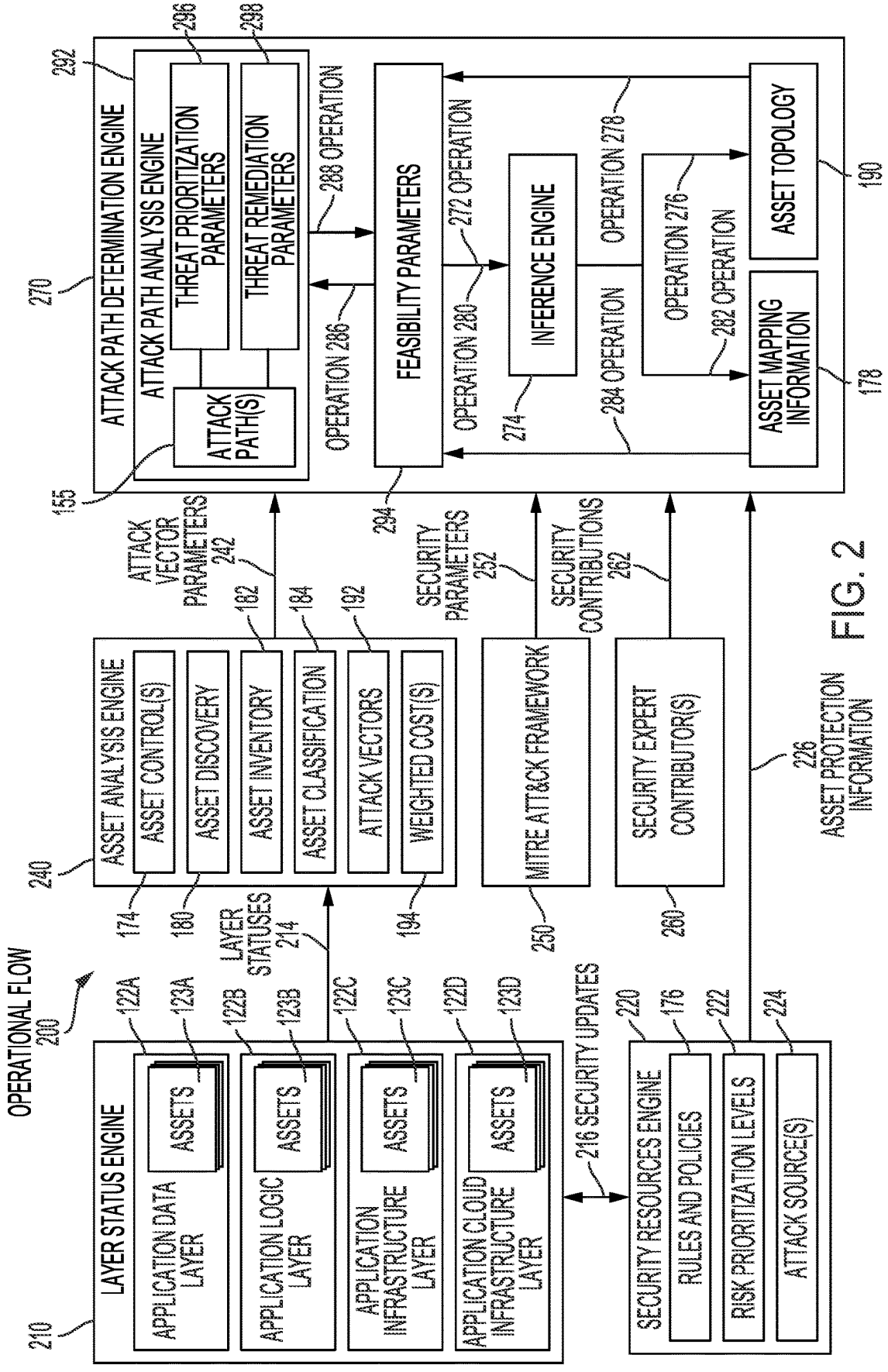

OPERATIONAL FLOW
200
210
LAYER STATUS ENGINE
APPLICATION DATA LAYER
ASSETS
APPLICATION LOGIC LAYER
APPLICATION INFRASTRUCTURE LAYER
APPLICATION CLOUD INFRASTRUCTURE LAYER
122A
123A
122B
123B
122C
123C
122D
123D
LAYER STATUSES 214
216 SECURITY UPDATES
220
176
222
224
SECURITY RESOURCES ENGINE
RULES AND POLICIES
RISK PRIORITIZATION LEVELS
ATTACK SOURCE(S)
240
ASSET ANALYSIS ENGINE
ASSET CONTROL(S)
ASSET DISCOVERY
ASSET INVENTORY
ASSET CLASSIFICATION
ATTACK VECTORS
WEIGHTED COST(S)
174
180
182
184
192
194
ATTACK VECTOR PARAMETERS 242
SECURITY PARAMETERS 252
SECURITY CONTRIBUTIONS 262
MITRE ATT&CK FRAMEWORK
SECURITY EXPERT CONTRIBUTOR(S)
250
260
226 ASSET PROTECTION INFORMATION
155
270
ATTACK PATH DETERMINATION ENGINE
292
ATTACK PATH ANALYSIS ENGINE
ATTACK PATH(S)
THREAT PRIORITIZATION PARAMETERS
THREAT REMEDIATION PARAMETERS
296
298
OPERATION 286
288 OPERATION
FEASIBILITY PARAMETERS
294
OPERATION 280
272 OPERATION
274
INFERENCE ENGINE
284 OPERATION
OPERATION 278
OPERATION 276
282 OPERATION
ASSET MAPPING INFORMATION
178
ASSET TOPOLOGY
190

FIG. 2

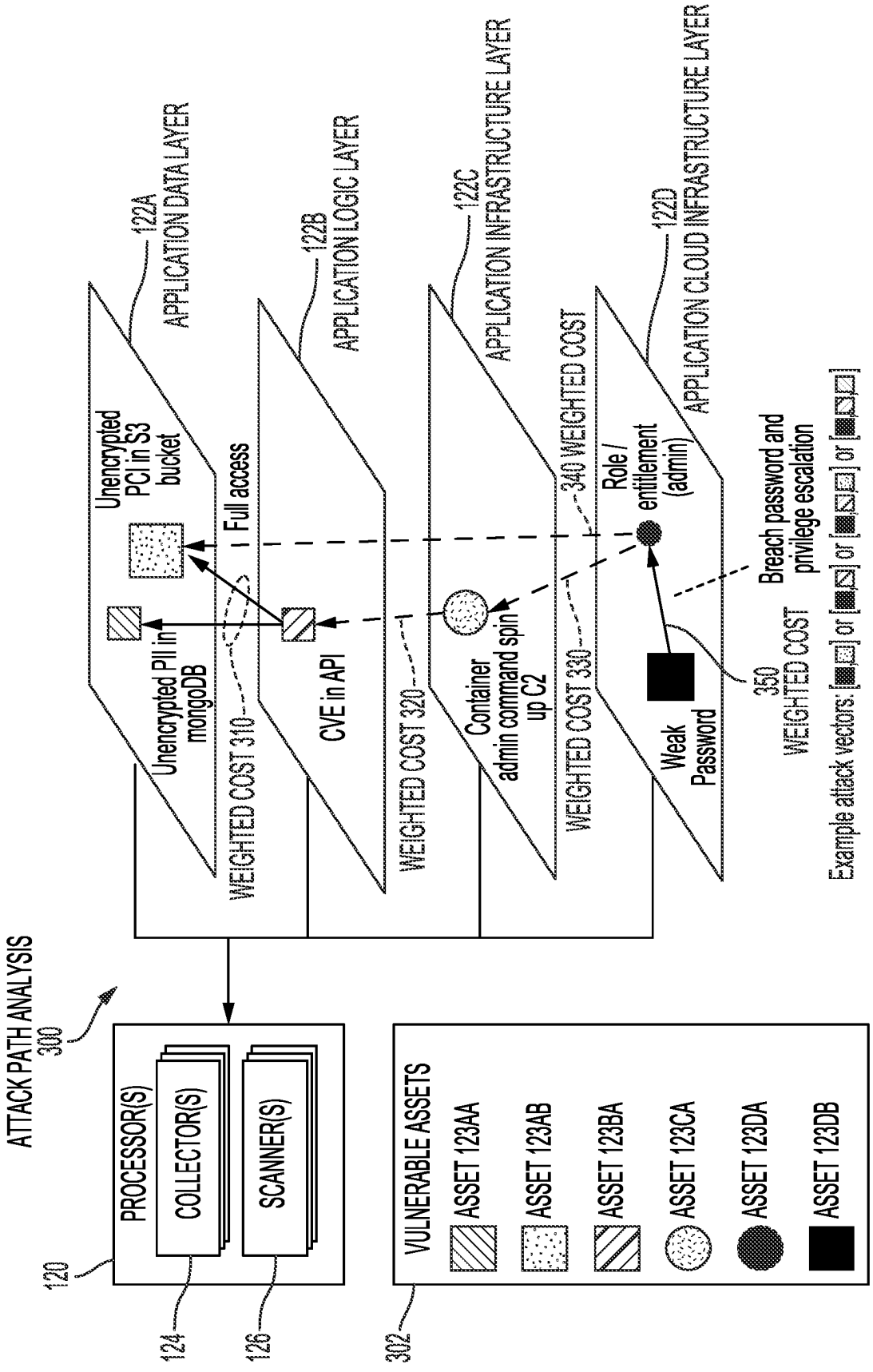

ATTACK PATH ANALYSIS
300
120
PROCESSOR(S)
COLLECTOR(S)
SCANNER(S)
124
126
VULNERABLE ASSETS
302
ASSET 123AA
ASSET 123AB
ASSET 123BA
ASSET 123CA
ASSET 123DA
ASSET 123DB
122A
APPLICATION DATA LAYER
122B
APPLICATION LOGIC LAYER
122C
APPLICATION INFRASTRUCTURE LAYER
122D
APPLICATION CLOUD INFRASTRUCTURE LAYER
Unencrypted PII in mongoDB
Unencrypted PCI in S3 bucket
Full access
CVE in API
Container admin command spin up C2
Weak Password
Role / entitlement (admin)
Breach password and privilege escalation
WEIGHTED COST 310
WEIGHTED COST 320
340 WEIGHTED COST
WEIGHTED COST 330
350
WEIGHTED COST
Example attack vectors: [ ] or [ ] or [ ] or [ ]

FIG. 3

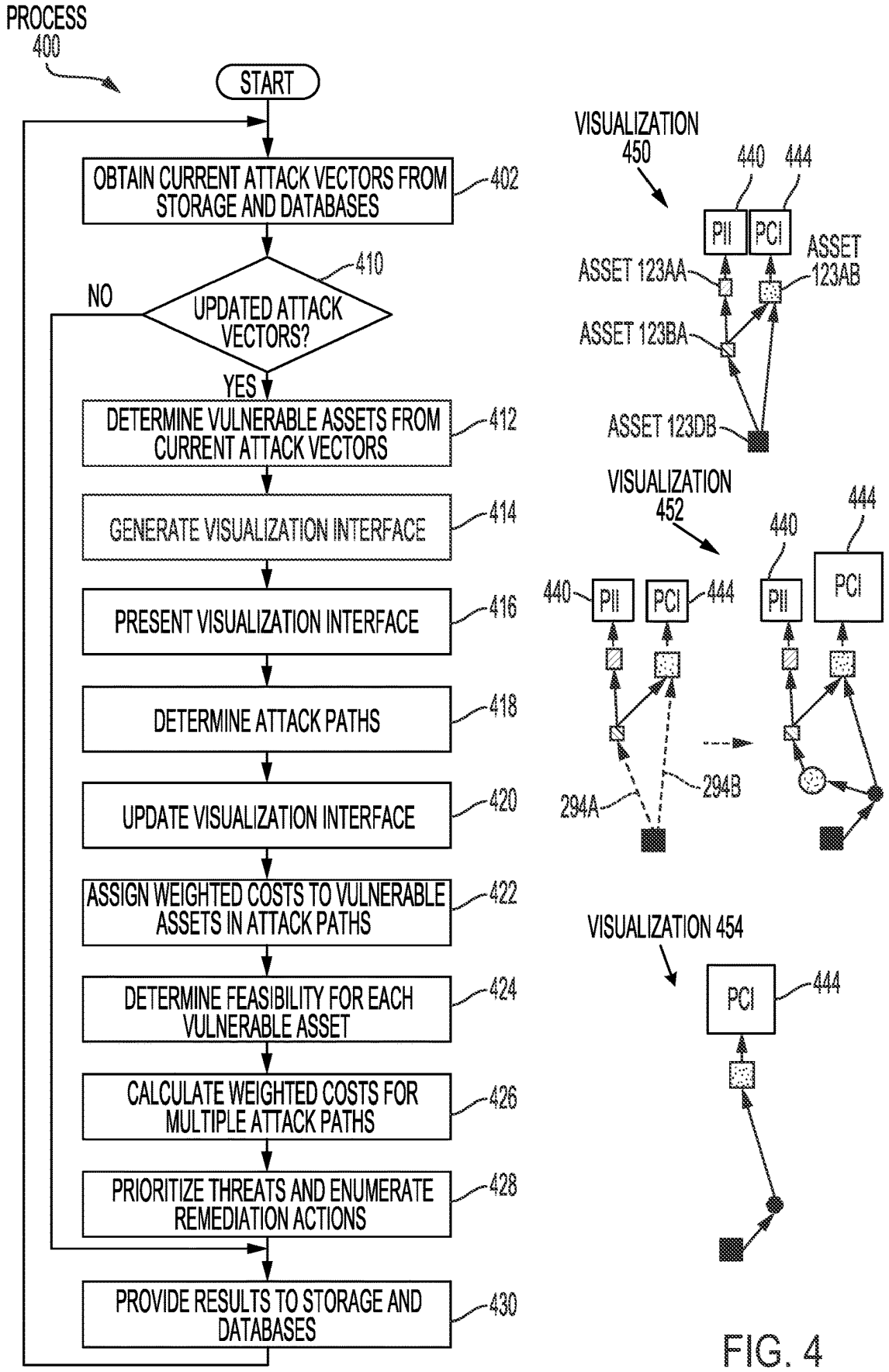

PROCESS
400
START
OBTAIN CURRENT ATTACK VECTORS FROM STORAGE AND DATABASES
402
410
NO
UPDATED ATTACK VECTORS?
YES
DETERMINE VULNERABLE ASSETS FROM CURRENT ATTACK VECTORS
412
GENERATE VISUALIZATION INTERFACE
414
PRESENT VISUALIZATION INTERFACE
416
DETERMINE ATTACK PATHS
418
UPDATE VISUALIZATION INTERFACE
420
ASSIGN WEIGHTED COSTS TO VULNERABLE ASSETS IN ATTACK PATHS
422
DETERMINE FEASIBILITY FOR EACH VULNERABLE ASSET
424
CALCULATE WEIGHTED COSTS FOR MULTIPLE ATTACK PATHS
426
PRIORITIZE THREATS AND ENUMERATE REMEDIATION ACTIONS
428
PROVIDE RESULTS TO STORAGE AND DATABASES
430
VISUALIZATION
450
440
444
PII
PCI
ASSET 123AA
ASSET 123AB
ASSET 123BA
ASSET 123DB
VISUALIZATION
452
440
444
PII
PCI
294A
294B
VISUALIZATION 454
PCI
444

FIG. 4

SYSTEMS AND METHODS TO DETERMINE ATTACK PATHS TO APPLICATION ASSETS

TECHNICAL FIELD

[0001] The present disclosure relates generally to a field of application asset protection, and more particularly, to a system and a method to determine attack paths to application assets.

BACKGROUND

[0002] Application assets (e.g., application data and application resources) are at risk of being exploited by bad actors. In some cases, data used by an application may be corrupted or stolen by these bad actors that destabilize security safeguards in one or more layers of the application. The bad actors may corrupt the data by modifying or copying the data in the application.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] For a more complete understanding of the present disclosure and for further features and advantages thereof, reference is now made to the following description taken in conjunction with the accompanying drawings, in which:

[0004] FIG. **1** illustrates an example system, according to some embodiments of the present disclosure;

[0005] FIG. **2** illustrates an example operational flow of the system of FIG. **1**, according to some embodiments of the present disclosure;

[0006] FIG. **3** illustrates an example attack path analysis for the system of FIG. **1**, according to some embodiments of the present disclosure; and

[0007] FIG. **4** illustrates an example process for performing the operational flow of FIG. **2**, according to some embodiments of the present disclosure.

DESCRIPTION OF EXAMPLE EMBODIMENTS

Overview

[0008] In one or more embodiments, a system and a method described herein determine attack paths to applications assets across multiple application layers of an application while providing a comprehensive understanding of vulnerabilities across the application layers. The system and the method prevent application assets (e.g., application data and application resources) from being at risk of being exploited by bad actors. In some embodiments, the system and the method may prevent data used by an application from being corrupted or stolen by these bad actors to destabilize security safeguards in one or more layers of the application. In other embodiments, the system and the method may prevent bad actors to modify or copy assets in the application. In this regard, the impact of potential attacks by these actors is drastically reduced in the application because the system and the method provide understanding and visualization of vulnerabilities across the application layers in attack paths.

[0009] In one or more embodiments, the system and the method comprise collecting different signals from multiple sources and using the signals as inputs to one or more processors implementing an inference engine. The system and the method may comprise applying different techniques such as ontological knowledge and semantic relatedness to reason on any data gathered from the signals received. The system and the method may comprise generating a converged topological view, persisting the topological view, and using the topological view as a new input into the one or more processors as a feedback for the implementation of the inference engine. The system and the method may comprise applying another technique to identify, categorize, and map possible attack vectors both within and across different application layers and assets. Herein, attack vectors are possible entry points for attacks by bad actors in one or more of the application layers of the application. The application layers may comprise an application data layer, an application logic layer, an application infrastructure layer, and an application cloud infrastructure layer. The system and the method may persist attack vector parameters comprising the attack vectors and using the application service, data topology, and any relevant attack vectors as an input for an attack path analysis engine implemented by the one or more processors. The one or more processors may implement the attack path analysis engine to determine one or all feasible attack paths across the application layers based at least in part upon the attack vector parameters.

[0010] In other embodiments, the system and the method provide application asset protection in distributed and complex applications. For example, the system and the method provide end-to-end visibility of possible vulnerabilities in applications comprising operations interconnected to cloud platforms such as Microsoft® Azure™, Google Cloud™, and Amazon Web Services®. The system and the method may determine vulnerable assets across multiple application layers, visualize location of sensitive assets in the application layers, and determine whether the sensitive assets are secure. In yet other embodiments, the system and the method may monitor statuses and association of the sensitive assets to one or more respective application layers. In this regard, the system and method may enable observability and security posture implementation for specific asset categories across multiple application layers.

[0011] In one or more embodiments, the system and the method combine multiple signals from multiple application layers, and other sources, such as cyberattack standards and human experts, as inputs to provide a multi-layer attack path analysis. In some embodiments, the multi-layer attack path analysis comprises determining feasibility of attack paths targeting any vulnerable asset in the multiple application layers. Further, the multi-layer attack path analysis may include detecting a least resistant path that a bad actor may follow to get access to vulnerable assets (e.g., sensitive data) as well as prioritization and remediation techniques operating in a closed-loop control.

[0012] In some embodiments, the system and the method generate multiple attack paths that provide visualization of a set of impact goals bad actors may attempt to realize (e.g., data compromise, CPU theft, and the like). In this regard, the system and the method determine cyberattack tactics and techniques that the bad actors may implement to construct attack paths to realize the impact goals. The system and the method may dynamically generate these attack paths by combining and recombining tactics and techniques. In other embodiments, the system and the method generate an application visualization interface (e.g., a graph) with all asset dependencies and interrelationships, where each of the assets in the visualization interface may include exploitable vulnerabilities. Further, the system and the method may generate the attack by crafting a path through the visualiza-

tion interface using lateral movement and privilege escalation across multiple layers of the application. Each attack path may be a representation of a starting point in which a bad actor may use an initial attack vector to get into one layer of the application and obtains additional access to realize an impact. At each vulnerable asset (e.g., node) the visualization interface may provide the impact that may be potentially realized by the bad actor.

[0013] In accordance with one or more embodiments, a system or an apparatus, such as a network component, includes a memory and a processor communicatively coupled to one another. The system may determine attack paths to application assets. The memory may store an asset inventory indicating multiple application assets, first attack vector parameters that indicate vulnerabilities of one or more of the application assets, and asset mapping information that associates each of the application assets to one or more of multiple application layers. The application layers may include an application data layer, an application logic layer, an application infrastructure layer, and an application cloud infrastructure layer. The processor may determine first vulnerable assets in the application assets based at least in part upon the first attack vector parameters, determine first feasibility parameters that indicate a first likelihood of the first attack path to occur in the system, generate a visual interface showing the vulnerable assets, and determine a first attack path connecting the first vulnerable assets based at least in part upon the asset mapping information. Further, the processor may map the first attack path to the application layers in the visual interface based at least in part upon the first feasibility parameters.

[0014] In some cases, the first feasibility parameters further indicate a first starting point of the first attack path.

[0015] In certain cases, the processor may further obtain second attack vector parameters, determine second vulnerable assets in the application assets based at least in part upon the second attack vector parameters, and generate the visual interface showing the first vulnerable assets and the second vulnerable assets. Further, the processor may determine a second attack path connecting the second vulnerable assets based at least in part upon the asset mapping information, determine second feasibility parameters that indicate a second likelihood of the second attack path to occur in the system, and map the second attack path to the application layers in the visual interface based at least in part upon the second feasibility parameters. The second feasibility parameters further indicate a second starting point of the second attack path.

[0016] In some cases, in conjunction with determining first vulnerable assets, the processor may further determine a first weighted cost to compromise the first vulnerable assets from the first attack path. Further, in conjunction with determining second vulnerable assets, the processor may further determine a second weighted cost to compromise the second vulnerable assets from the second attack path, determine whether the first weighted cost is greater than the second weighted cost, and prioritize remediation for the second attack path in response to determining that the first weighted cost is greater than the second weighted cost. The processor may prioritize remediation for the first attack path in response to determining that the second weighted cost is greater than the first weighted cost.

[0017] In yet other cases, in response to the second weighted cost being greater than the first weighted cost, the processor may generate first threat prioritization parameters that indicate first corresponding priorities for each vulnerable asset in the first vulnerable assets, generate first remediation parameters that indicate a first solution to remediate the first attack path in the system, and assign the first threat prioritization parameters and the first remediation parameters to the first attack path in the visual interface. In response to the first weighted cost being greater than the second weighted cost, the processor may generate second threat prioritization parameters that indicate second corresponding priorities for each vulnerable asset in the second vulnerable assets, generate second remediation parameters that indicate a second solution to remediate the second attack path in the system, and assign the second threat prioritization parameters and the second remediation parameters to the second attack path in the visual interface.

[0018] In one or more embodiments, the first attack vector parameters may comprise a comprehensive list of attack vectors. Further, the first attack vector parameters may comprise information indicating vulnerabilities and potential intrusions in the application layers.

[0019] In accordance with other embodiments, a method comprises determining attack paths to application assets. The method may comprise obtaining multiple parameters comprising asset inventory indicating multiple application assets, attack vector parameters that indicate vulnerabilities of one or more of the application assets, and asset mapping information that associate each of the application assets to one or more application layers. The application layers may include an application data layer, an application logic layer, an application infrastructure layer, and an application cloud infrastructure layer. Further, the method may comprise determining multiple vulnerable assets in the application assets based at least in part upon the attack vector parameters, determining first feasibility parameters that indicate a first likelihood of the first attack path to occur in the system, generating a visual interface showing the vulnerable assets, determining an attack path connecting the vulnerable assets based at least in part upon the asset mapping information, and mapping the attack path to the application layers in the visual interface based at least in part upon the first feasibility parameters.

[0020] In accordance with yet other embodiments, a non-transitory computer readable medium stores instructions that when executed by a processor cause the processor to determine attack paths to application assets. The instructions may further cause the processor to obtain multiple parameters comprising asset inventory indicating multiple application assets, attack vector parameters that indicate vulnerabilities of one or more of the application assets, and asset mapping information that associate each of the application assets to one or more application layers. The application layers may include an application data layer, an application logic layer, an application infrastructure layer, and an application cloud infrastructure layer. The instructions may cause the processor to determine multiple vulnerable assets in the application assets based at least in part upon the attack vector parameters, determine first feasibility parameters that indicate a first likelihood of the first attack path to occur in the system, generate a visual interface showing the vulnerable assets, determine a first attack path connecting the vulnerable assets based at least in part upon the asset mapping information,

and map the first attack path to the application layers in the visual interface based at least in part upon the first feasibility parameters.

[0021] Technical advantages of certain embodiments of this disclosure may include one or more of the following. The system and the method described herein determine attack paths to application assets associated with one or more application layers in a multi-layer application. Specifically, the system and the method reduce and prevent exposure to attacks from bad actors by providing visibility to vulnerable assets across the multiple application layers. In particular, the system and the method reduce or eliminate potential attacks from bad actors by enabling remediation of potential attacks at multiple entry levels in the application layers. As a result, vulnerabilities of assets may be reduced or eliminated before bad actors have an opportunity to exploit vulnerable assets.

[0022] In addition, the system and method described herein are integrated into a practical application of increasing processing speed and reducing memory usage in the system. Specifically, the system and the method reduce or eliminate delays or data congestions caused by attacks involving application assets. Further, the system and the method are integrated into a practical application of reducing an overall amount of network traffic due to pausing of application transmissions and operations resulting from bad actor interruptions. This reduces the traffic on the network and helps alleviate network bottlenecks that could otherwise occur during operations requiring multiple-layer application asset operations such as those involving Artificial Intelligence (AI) and Machine Learning (ML) procedures.

[0023] These practical applications may lead to a technical advantage of improving response speed and accuracy to user devices. For example, a technical advantage of one embodiment may allow for improved reliability in real-time communications between a client device and a server in which the application comprises one or more assets. In another example, another technical advantage of one embodiment may identify critical threats detected by the attack path analysis, prioritize these threats, and provide detailed steps enabling remediation actions to mitigate, reduce, or eliminate the threats.

[0024] Other technical advantages will be readily apparent to one skilled in the art from the following figures, descriptions, and claims. Moreover, while specific advantages have been enumerated above, various embodiments may include all, some, or none of the enumerated advantages.

Example Embodiments

[0025] This disclosure describes systems and methods to determine attack paths to application assets associated with one or more application layers in a multi-layer application. In particular, this disclosure provides various systems and methods to reduce, prevent, or eliminate unsanctioned access to vulnerable assets of a multi-layered application structure by providing understanding, prioritization, and visualization of risks and attacks caused by bad actors in the application. FIG. **1** illustrates a system **100** in which one or more application layers **122** are analyzed to determine one or more attack paths **155** to application assets **123**. FIG. **2** illustrates an operational flow **200** in which the system **100** of FIG. **1** is configured to implement an attack path analysis engine **292**. FIG. **3** illustrates an attack path analysis **300** performed via the attack path analysis engine **292** of FIG. **2**. FIG. **4** illustrates a process **400** to perform the operational flow **200** of FIG. **2**.

[0026] FIG. **1** illustrates a system **100** configured to determine attack paths **155** to application assets **123**, in accordance with one or more embodiments. The application assets **123** may be configured as part of an application that routes control commands and data signals among at least one network component **102**, one or more client devices **106**, and a network **104**. In the system **100** of FIG. **1**, the network component **102**, the one or more client devices **106**, and the network **104** are communicatively coupled to one another via multiple communication paths **110-114**. For example, FIG. **1** shows that: the network component **102** and the network **104** are connected to one another via the communication path **110**; the network component **102** and the one or more client devices **106** are connected to one another via the communication path **112**; and the network **104** and the one or more client devices **106** are connected to one another via the communication path **114**. The communication paths **110-114** may be wired or wireless connections among the at least one network component **102**, the one or more client devices **106**, or the network **104**. In one or more embodiments, the network component **102** may be a hardware chassis configured to control data flow. The network component **102** may be configured to regulate data packet transmissions in the communication path **110** or the communication path **112**. The communication paths **110-114** may include multiple bandwidth levels in which control signals and data signals may be transmitted using one or more communication protocols.

[0027] In one or more embodiments, the network **104** and the one or more client devices **106** may be a source or a destination for data packet transmissions monitored or controlled by one or more processors **120**. In this regard, the communication interface **140** receives or transmits data packet transmissions exchanged with the network **104** via the communication path **110** and exchanged with the one or more client devices **106** via the communication path **112**. The network component **102** may include the one or more processors **120**, a memory **170**, an input (I)/output (O) interface **130**, a communication interface **140**, and storage and databases **150** connected to one another via an interconnect **160**. The network component **102** may be a computer system used to provide routing and assignment of resources during data packet transmissions. In one or more embodiments, one or more memory elements (e.g., the memory **170**) may be shared by the one or more processors **120** in the network component **102**. The one or more processors **120** in the network component **102** may be adapted to perform basic and advanced packet counting and forwarding operations. Although this disclosure describes and illustrates a particular network component **102** having a particular number of particular components in a particular arrangement, this disclosure contemplates any suitable network component **102** or computer system having any suitable number of any suitable components in any suitable arrangement.

[0028] In some embodiments, the network component **102** may take any suitable physical form. As example and not by way of limitation, the network component **102** may be an embedded computer system, a system-on-chip (SOC), a single-board computer (SBC) system (such as, for example, a computer-on-module (COM) or system-on-module

(SOM)), a desktop computer system, a laptop or notebook computer system, an interactive kiosk, a mainframe, a mesh of computer systems, a mobile telephone, a personal digital assistant (PDA), a server, a tablet computer system, an augmented/virtual reality device, a router device, or a combination of two or more of these. Where appropriate, the network component **102** may include one or more computer systems; be unitary or distributed; span multiple locations; span multiple machines; span multiple data centers; or reside in a cloud, which may include one or more cloud components in one or more networks. Where appropriate, one or more computer systems may perform without substantial spatial or temporal limitation one or more steps of one or more methods described or illustrated herein. As an example, and not by way of limitation, the network component **102** may perform in real-time or in batch mode one or more steps of one or more methods described or illustrated herein. The network component **102** may perform at different times or at different locations one or more steps of one or more methods described or illustrated herein, where appropriate.

[0029] In some embodiments, the one or more processors **120** includes hardware for executing instructions, such as those making up a computer program. As an example, and not by way of limitation, to execute instructions, the one or more processors **120** may retrieve (or fetch) the instructions from an internal register, an internal cache, or the memory **170**; decode and execute them; and then write one or more results to an internal register, an internal cache, or the memory **170**. Specifically, the one or more processors **120** may include one or more internal caches for data, instructions, or addresses. This disclosure contemplates the one or more processors **120** including any suitable number of internal caches, where appropriate. As an example, and not by way of limitation, the one or more processors **120** may include one or more instruction caches, one or more data caches, and one or more translation lookaside buffers (TLBs). Instructions in the instruction caches may be copies of instructions **172** in the memory **170**, and the instruction caches may speed up retrieval of those instructions by the one or more processors **120**. Data in the data caches may be copies of data in the memory **170** for instructions executing at the one or more processors **120** to operate on via one or more processing engines **128**; the results of previous instructions executed at the one or more processors **120** for access by subsequent instructions executing at the one or more processors **120** or for writing to the memory **170**; or other suitable data. The data caches may speed up read or write operations by the one or more processors **120**. The TLBs may speed up virtual-address translation for the one or more processors **120**. In particular embodiments, the one or more processors **120** may include one or more internal registers for data, instructions, or addresses. This disclosure contemplates the one or more processors **120** including any suitable number of suitable internal registers, where appropriate. Where appropriate, the one or more processors **120** may include one or more arithmetic logic units (ALUs); be a multi-core processor; or include one or more additional one or more processors **120**. Although this disclosure describes and illustrates a particular processor, this disclosure contemplates any suitable processor.

[0030] In one or more embodiments, the one or more processors **120** include hardware, software executed by hardware, or a combination of both, providing one or more service components to route and assign resources for data packet transmissions. The one or more processors **120** may include access to the one or more application layers **122**, one or more collectors **124**, one or more scanners **126**, and one or more processing engines **128** communicatively coupled to one another or interconnected via a transmission bus (not shown, but similar to the interconnect **160** described below). The one or more processors **120** may be a routing device configured to route resources in the network **104** to the one or more client devices **106**. In some embodiments, the one or more processors **120** may be included on a same card or die. In this regard, the access to the application layers **122** may comprise one or more access to multiple assets **123** performing one or more operations in an application. The collectors **124** and the scanners **126** may be configured to retrieve one or more asset parameters from the one or more application layers **122**. The asset parameters may comprise information indicating monitored statuses for each of the application layers **122**. The collectors **124** and the scanners **126** may be centralized or distributed (e.g., deployed under control of asset owners, application controls, or application management). In some embodiments, collectors **124** and the scanners **126** support continuous scanning and/or collection capability both in an active mode and a passive mode. In one example, the asset parameters may be signals collected or scanned during one or more run time environments (e.g., active mode). In another example, the asset parameters may be signals collected by importing files (e.g., passive mode) or through application programming interfaces (APIs). In yet another example, the asset parameters may be signals obtained in multiple ways, such as by scanning via a plugin interface or collected via an upload process or operation.

[0031] In other embodiments, the one or more processing engines **128** may be software executed by hardware and configured to determine attack paths to application assets **123** based at least in part on the asset parameters obtained from the application layers **122**. The one or more processing engines **128** are described in more detail in reference to FIG. **2**. The one or more processing engines **128** may be implemented by the one or more processors **120** operating as specialized hardware accelerators. The one or more processing engines **128** may be configured to implement networking-specific processing tasks in custom logic and achieve better performance than typical software implementations. For example, the one or more processing engines **128** may be lookup engines (e.g., using specialized logic), cryptographic coprocessors, content inspection engines, and the like. In some embodiments, the one or more processing engines **128** comprise a layer status engine **210**, a security resources engine **220**, an asset analysis engine **240**, an attack path determination engine **270**, and an attack path analysis engine **292**.

[0032] In one or more embodiments, the I/O interface **130** comprises hardware, software executed by hardware, or a combination of both, providing one or more interfaces for communication between the network component **102** and one or more I/O devices. The network component **102** may include one or more of these I/O devices, where appropriate. One or more of these I/O devices may enable communication between a person and the network component **102**. As an example, and not by way of limitation, an I/O device may include a keyboard, keypad, microphone, monitor, mouse, printer, scanner, speaker, still camera, stylus, tablet, touch screen, trackball, video camera, another suitable I/O device,

or a combination of two or more of these. An I/O device may include one or more sensors. This disclosure contemplates any suitable I/O devices and any suitable I/O interfaces **130** for them. Where appropriate, I/O interface **130** may include one or more device or software drivers enabling the one or more processors **120** to drive one or more of these I/O devices. The I/O interface **130** may include one or more I/O interfaces **130**, where appropriate. Although this disclosure describes and illustrates a particular I/O interface **130**, this disclosure contemplates any suitable I/O interface **130**.

[0033] In one or more embodiments, the communication interface **140** includes hardware, software executed by hardware, or a combination of both providing one or more interfaces for communication (such as, for example, packet-based communication) between the network component **102**, the one or more client devices **106**, the network **104**, or one or more additional networks. As an example, and not by way of limitation, the communication interface **140** may include a network interface controller (NIC) or network adapter for communicating with an Ethernet or other wire-based network or a wireless NIC (WNIC) or wireless adapter for communicating with a wireless network, such as a WI-FI network. This disclosure contemplates any suitable network and any suitable corresponding communication interface **140**. As an example, and not by way of limitation, the network component **102** may communicate with an ad hoc network, a personal area network (PAN), a local area network (LAN), a wide area network (WAN), a metropolitan area network (MAN), or one or more portions of the Internet or a combination of two or more of these. One or more portions of one or more of these networks may be wired or wireless. As an example, the network component **102** may communicate with a wireless PAN (WPAN) (such as, for example, a Bluetooth WPAN), a WI-FI network, a WI-MAX network, a cellular telephone network (such as, for example, a Global System for Mobile Communications (GSM) network, a Long-Term Evolution (LTE) network, or a 5G network), or other suitable wireless network or a combination of two or more of these. The network component **102** may include any suitable communication interface **140** for any of these networks, where appropriate. The communication interface **140** may include one or more communication interfaces **140**, where appropriate. Although this disclosure describes and illustrates a particular communication interface, this disclosure contemplates any suitable communication interface.

[0034] In some embodiments, the storage and databases **150** may be communicatively coupled to the one or more processors **120**, the I/O interfaces **130**, the communication interfaces **140**, and the memory **170**. The storage and databases **150** may be a wired connection that shares an internal bandwidth for data packet transmissions inside the network component **102** with the memory **170**. The storage and databases **150** may be configured with an internal buffering capacity and an internal memory speed. The internal buffering capacity may indicate a buffering capacity (in bytes) that the storage and databases **150** are capable of handling. For example, the internal buffering capacity may be 1,000 bytes. Further, the internal memory speed may indicate a processing speed (in bytes per second) at which the storage and databases **150** is capable of handling or buffering data packets. For example, the internal memory speed may be 1,000 bytes per second. The storage and databases **150** may comprise instructions and data memory for the one or more processors **120**. In other embodiments, some portions of the memory are shared among the one or more processors **120** and the memory **170**. The storage and databases **150** may comprise one or more attack paths **155** representative of a sequence of vulnerable assets **123** that an attack vector may follow to impact the integrity of the application. Each attack path of the attack paths **155** may be configured to provide visibility and understanding of vulnerable assets **123** across the multiple application layers **122**.

[0035] In particular embodiments, the interconnect **160** includes hardware configured to couple components of the network component **102** to each other. As an example and not by way of limitation, the interconnect **160** may include an Accelerated Graphics Port (AGP) or a graphics bus, an Enhanced Industry Standard Architecture (EISA) bus, a front-side bus (FSB), a HyperTransport (HT) interconnect, an Industry Standard Architecture (ISA) bus, an InfiniBand interconnect, a low-pin-count (LPC) bus, a memory bus, a Micro Channel Architecture (MCA) bus, a Peripheral Component Interconnect (PCI) bus, a PCI-Express (PCIe) bus, a serial advanced technology attachment (SATA) bus, a Video Electronics Standards Association local (VLB) bus, or another suitable bus or a combination of two or more of these. The interconnect **160** may include one or more interconnect **160**, where appropriate. Although this disclosure describes and illustrates a particular bus, this disclosure contemplates any suitable bus or interconnect.

[0036] The interconnect **160** may be one or more memory buses (which may each include an address bus and a data bus) that may couple the one or more processors **120** to the memory **170**. In other embodiments, one or more memory management units (MMUs) reside between the one or more processors **120** and the memory **170** and facilitate accesses to the memory **170** requested by the one or more processors **120**. In particular embodiments, the memory **170** includes random access memory (RAM). This RAM may be volatile memory, where appropriate. Where appropriate, this RAM may be dynamic RAM (DRAM) or static RAM (SRAM). Moreover, where appropriate, this RAM may be single-ported or multi-ported RAM. This disclosure contemplates any suitable RAM. The memory **170** may include one or more additional memories, where appropriate. Although this disclosure describes and illustrates particular memories, this disclosure contemplates any suitable memory or combination of suitable memories.

[0037] In particular embodiments, the memory **170** includes mass storage for data or instructions. As an example, and not by way of limitation, the memory **170** may include a hard disk drive (HDD), a floppy disk drive, flash memory, an optical disc, a magneto-optical disc, magnetic tape, or a Universal Serial Bus (USB) drive or a combination of two or more of these. The memory **170** may include removable or non-removable (or fixed) media, where appropriate. The memory **170** may be internal or external to a computer system, where appropriate. In particular embodiments, the memory **170** is non-volatile, solid-state memory. In particular embodiments, the memory **170** includes read-only memory (ROM). Where appropriate, this ROM may be mask-programmed ROM, programmable ROM (PROM), erasable PROM (EPROM), electrically erasable PROM (EEPROM), electrically alterable ROM (EAROM), or flash memory or a combination of two or more of these. This disclosure contemplates the memory **170** as a mass storage

taking any suitable physical form. The memory **170** may include one or more storage control units facilitating communication between the one or more processors **120** and the memory **170**, where appropriate. Although this disclosure describes and illustrates particular storage, this disclosure contemplates any suitable storage.

[0038] In one or more embodiments, the memory **170** includes a main memory for storing the instructions **172** for the one or more processors **120** to execute or data for the one or more processors **120** to operate on. As an example, and not by way of limitation, the network component **102** may load the instructions **172** from another memory in the network component **102**. The one or more processors **120** may then load the instructions **172** from the memory **170** to an internal register or internal cache. To execute the instructions **172**, the one or more processors **120** may retrieve the instructions **172** from the internal register or internal cache and decode them. During or after execution of the instructions **172**, the one or more processors **120** may write one or more results (which may be intermediate or final results) to the internal register or internal cache. The one or more processors **120** may then write one or more of those results to the memory **170**. In some embodiments, the one or more processors **120** executes only the instructions **172** in one or more internal registers or internal caches or in the memory **170** and operates only on data in one or more internal registers or internal caches or in the memory **170**.

[0039] In one or more embodiments, the memory **170** includes commands or data associated with one or more specific applications in addition or as part of the instructions **172**. In FIG. **1**, the memory **170** comprises the one or more asset controls **174**, multiple rules and policies **176**, asset mapping information **178**, asset discovery **180**, asset inventory **182**, asset classification **184**, attack path analysis information **186**, asset topology **190**, attack vectors **192**, one or more weighted costs **194**, and security and safety information **196**. In some embodiments, the one or more asset controls **174** may be configured to provide one or more connectivity parameters to establish a connection between the one or more processors **120** and the application layers **122**. The one or more asset controls **174** may be configured to provide access to assets **123** in the application layers **122**. For example, the one or more asset controls **174** may be one or more preestablished commands that the collectors **124** and the scanners **126** may use to obtain the monitoring statuses from the application layers **122**.

[0040] In some embodiments, the multiple rules and policies **176** may be information commanding rules and/or operations of the system **100**. The rules and policies **176** may be updated dynamically or periodically over time. For example, the rules and policies **176** may provide guidelines to access, receive and transmit information using the network component **102**. In other embodiments, the asset mapping information **178** comprises mapping tools that enables mapping of assets **123** in the application layers **122** when implemented by the one or more processors **120**. The asset discovery **180** may be information to find existing assets **123** in the application layers **122**. The asset inventory **182** may be configured to provide information indicating names or identifiers for the assets **123** in the application layers **122**. The asset classification **184** may be configured to provide relation information between the assets **123** and any corresponding application layers **122**.

[0041] In one or more embodiments, the attack path analysis information **186** may be configured to provide attack path information generated via the one or more processing engines **128**. In some embodiments, the attack path analysis information **186** is the basis to analyze the attack paths **155** and any corresponding impact to one or more assets **123** in the application layers **122**. In other embodiments, the attack path analysis information **186** may be risk associated factors indicating a level or risk associated with any one segment of a specific attack path **155**. In some embodiments, the asset topology **190** may be configured to associate assets **123** among one another. For example, the asset topology **190** may comprise relation information among one or more assets **123**. The asset topology **190** may be dynamically modified based at least in part upon changes to operations or structures in the application layers **122** of the application.

[0042] In some embodiments, the attack vectors **192** may be configured to represent a sequence of vulnerabilities that may be exploited by bad actors (e.g., attackers or hackers) to gain access to application assets **123** in order to deliver a payload or a malicious outcome (e.g., exfiltrate data, ransomware, or cyberattacks against the application). Each vulnerability may be seen as an attack vector or an element of an attack vector **192**. In certain embodiments, a vulnerability may be part of several attack vectors **192**. The attack vectors **192** may be unencrypted data from data security posture management (DSPM). In other embodiments, the attack paths **155** are visual representations of specific chains of actions or events that may occur when the attack vectors **192** are exploited in a given application instance and configuration context.

[0043] In some embodiments, the one or more weighted costs **194** may be configured to represent a difficulty for an attacker to make a transition between any two assets by exploiting a detected attack vector **192**. A higher weighted cost **194** may represent a higher difficulty to transition between assets and a lower weighted cost **194** may represent a lower difficulty to transition between the assets. Further, the weighted costs **194** may be configured to represent monetary or organizational impacts resulting from unsanctioned access to the assets **123** to the application. The weighted costs **194** may be different or the same for different segments of a given attack path **155**. Further, the weighted costs may be different or the same for different attack paths **155**. For example, a first attack path of the attack paths **155** may comprise multiple segments. In this case, each segment may comprise a corresponding weighted cost **194**. The security and safety information **196** may be a database comprising knowledge of tactics and techniques designed for threat hunters, defenders and red teams to classify attacks, identify attack attribution and objectives, and assess risks for a given organization. In some embodiments, the given organization may use a framework to identify security gaps and prioritize mitigations based on the assessed risks.

[0044] One or more of the asset controls **174**, the rules and policies **176**, the asset mapping information **178**, the asset discovery **180**, the asset inventory **182**, the asset classification **184**, the attack path analysis information **186**, the asset topology **190**, the attack vectors **192**, the weighted costs **194**, and the security and safety information **196** may be configured to be used or updated as part of the operational flow **200** described in reference to FIG. **2**.

[0045] Herein, a computer-readable non-transitory storage medium or media may include one or more semiconductor-

based or other integrated circuits (ICs) (such, as for example, field-programmable gate arrays (FPGAs) or application-specific ICs (ASICs)), hard disk drives (HDDs), hybrid hard drives (HHDs), optical discs, optical disc drives (ODDs), magneto-optical discs, magneto-optical drives, floppy diskettes, floppy disk drives (FDDs), magnetic tapes, solid-state drives (SSDs), RAM-drives, SECURE DIGITAL cards or drives, any other suitable computer-readable non-transitory storage media, or any suitable combination of two or more of these, where appropriate. A computer-readable non-transitory storage medium may be volatile, non-volatile, or a combination of volatile and non-volatile, where appropriate.

[0046] In one or more embodiments, the network **104** may be a combination of electronic devices forming a multi-node mesh. As an example and not by way of limitation, one or more portions of the network **104** may include an ad hoc network, an intranet, an extranet, a virtual private network (VPN), a LAN, a wireless LAN (WLAN), a WAN, a wireless WAN (WWAN), a MAN, a portion of the Internet, a portion of the Public Switched Telephone Network (PSTN), a cellular technology-based network, a satellite communications technology-based network, another network **104**, or a combination of two or more such networks **104**.

[0047] In one or more embodiments, the one or more client devices **106** include end-user devices such as laptops, phones, tablets, and any other suitable device that are capable of receiving, creating, processing, storing, or communicating information, including data packet transmissions. The client devices **106** may comprise one or more network interfaces, at least one processor, and a memory that is interconnected by a system bus as well as a power supply. In some embodiments, the client devices **106** represents devices that are capable of receiving real-time data packet transmissions and may include general purpose computing devices (e.g., servers, workstations, desktop computers, and the like), mobile computing devices (e.g., laptops, tablets, mobile phones, and the like), wearable devices (e.g., watches, glasses, or other head-mounted displays (HMDs), ear devices, and the like), and so forth. The client devices **106** may also include Internet of Things (IoT) devices or equipment, such as agricultural equipment (e.g., livestock tracking and management systems, watering devices, unmanned aerial vehicles (UAVs), and the like); connected cars and other vehicles; smart home sensors and devices (e.g., alarm systems, security cameras, lighting, appliances, media players, Heating Ventilation, and Air Conditioning (HVAC) equipment, utility meters, windows, automatic doors, door bells, locks, etc.); office equipment (e.g., desktop phones, copiers, fax machines, and the like); healthcare devices (e.g., pacemakers, biometric sensors, medical equipment, and the like); industrial equipment (e.g., robots, factory machinery, construction equipment, industrial sensors, and the like); retail equipment (e.g., vending machines, point of sale (POS) devices, Radio Frequency Identification (RFID) tags, and the like); smart city devices (e.g., street lamps, parking meters, waste management sensors, and the like); transportation and logistical equipment (e.g., turnstiles, rental car trackers, navigational devices, inventory monitors, and the like); and so forth.

[0048] FIG. **2** shows an example operational flow **200** to determine attack paths **155** to application assets **123** associated with one or more application layers **122** in the system **100** of FIG. **1**, in accordance with one or more embodiments. In FIG. **2**, the operational flow **200** is performed by different components in the network component **102**. In particular, the operational flow **200** may be performed using the one or more processors **120**. As a non-limiting example, the communication interface **140** may be a source of data packet transmissions into the network component **102** via the communication path **110** and the communication path **112**. The communication interface **140** may also transfer data packet transmissions outside from the network component **102** via the communication path **110** and the communication path **112**. In some embodiments, the operational flow **200** is performed via implementation of the one or more processing engines **128**, which may comprise a layer status engine **210**, a security resources engine **220**, an asset analysis engine **240**, an attack path determination engine **270**, and an attack path analysis engine **292** communicatively coupled to one another. As described above, the layer status engine **210**, the security resources engine **220**, the asset analysis engine **240**, the attack path determination engine **270**, and the attack path analysis engine **292** may be implemented via the one or more processors **120**.

[0049] The layer status engine **210** may be configured to retrieve monitored statuses collected and scanned via the collectors **124** and the scanners **126**, respectively. The collectors **124** and the scanners **126** may be configured to track vulnerabilities from the assets **123** in the application layers **122**. In the example of FIG. **2**, the collectors **124** and the scanners **126** monitor statuses of the assets **123**A in the application data layer **122**A; the assets **123**B in the application logic layer **122**B; the assets **123**C in the application infrastructure layer **122**C; and the assets **123**D in the application cloud infrastructure layer **122**D. The layer status engine **210** may be configured to establish one or more security updates **216** with the security resources engine **220**. In this regard, the layer status engine **210** may be configured to provide layer statuses **214** to the asset analysis engine **240** based at least in part upon the security updates **216** established with the layer status engine **210**.

[0050] In one or more embodiments, the security resources engine **220** comprises the rules and policies **176**, one or more risk prioritization levels **222**, and one or more attack sources **224**. The security resources engine **220** may be configured to establish the security updates **216** with the layer status engine **210** based at least in part upon the rules and policies **176**. The risk prioritization levels **222** may be configured to provide a prioritization for a vulnerable asset **123** in the application. For example, the risk prioritization levels **222** may indicate a relevance of one or more assets **123** to the overall application or to one of the application layers **122**. In another example, security resources engine **220** may indicate a first prioritization level **222** for a first vulnerable asset **123** comprising access to databases with personally identifiable information (PII) and a second prioritization level **222** for a second vulnerable asset **123** comprising a breach to steal CPU (e.g., CPU steal time for cryptomining). The attack sources **224** may be indicative of possible starting points for one or more of the attack vectors **192**. In some embodiments, the security resources engine **220** may be configured to provide asset protection information **226** to the attack path determination engine **270** based at least in part upon the security updates **216** established with the layer status engine **210**. The asset protection information **226** may comprise the risk prioritization levels

222 in association with one or more of the attack sources 224. The asset analysis engine 240 may be configured to generate multiple attack vector parameters 242 based at least in part upon the asset controls 174, the asset discovery 180, the asset inventory 182, the asset classification 184, the attack vectors 192, and the weighted costs 194.

[0051] The attack path determination engine 270 may be configured to determine attack paths to one or more of the application assets 123. The attack path determination engine 270 may receive the attack vector parameters 242 from the asset analysis engine 240, one or more security parameters 252 from a MITRE ATT&CK framework 250, one or more security contributions 262 from one or more security expert contributors 260, and the asset protection information 226 from the security resources engine 220. The attack vector parameters 242 may be configured to indicate vulnerabilities of one or more of the plurality of application assets.

[0052] The MITRE ATT&CK framework 250 may be associated with MITRE ATT&CK®, which stands for MITRE Adversarial Tactics, Techniques, and Common Knowledge (ATT&CK). The MITRE ATT&CK framework 250 is a curated knowledge base and model for cyber adversary behavior, reflecting various phases of attack lifecycles and attack targets for bad actors. The MITRE ATT&CK framework 250 may provide a common taxonomy of individual adversary actions by both offensive and defensive sides of cybersecurity. Further, the security contributions 262 may comprise additional information for identifying tactics and techniques such as reconnaissance, resource development, initial access, execution, persistence, privilege escalation, defense evasion, credential access, discovery, lateral movement, collection, command and control, exfiltration and impact tactics and techniques. As non-limiting examples, the reconnaissance tactics and techniques may involve bad actors actively or passively gathering information that could be used to support targeting. The resource development tactics and techniques may involve bad actors creating, purchasing, or compromising/stealing resources that could be used to support targeting. The initial access tactics and techniques may comprise gaining initial footholds within the network 104 via targeted spearphishing and exploiting weaknesses on public-facing assets 123. The execution tactics and techniques may comprise adversary-controlled code running on a local or a remote system paired with techniques from all other tactics to achieve broader goals, like exploring a network or stealing data. The persistence tactics and techniques may comprise techniques that bad actors may use to keep access to systems across restarts, changed credentials, and other interruptions that could cut off access to the bad actors. The privilege escalation tactics and techniques may comprise bad actors attempting to gain higher-level permissions on a system or network. The defense evasion tactics and techniques may be comprise bad actors attempting to avoid detection throughout attacks. The credential access tactics and techniques may comprise bad actors attempting to steal credentials or access information like account names and passwords. The discovery tactics and techniques may comprise bad actors attempting to gain knowledge about internal architectures of systems and networks. The lateral movement tactics and techniques may comprise bad actors that attempt to enter and control remote systems on a network. The collection tactics and techniques may comprise bad actors attempting to gather information from the application. The command and control tactics and techniques may comprise bad actors that communicate with systems under a guise of management and control. The exfiltration tactics and techniques may comprise bad actors attempting to steal data from the application. The impact tactics and techniques may comprise bad actors attempting to disrupt availability or compromise integrity of operational processes in the application.

[0053] The security expert contributors 260 may be one or more contributions from security organizations comprising expertise in the areas of application defense and cybersecurity among others. The security expert contributors 260 may be configured to provide additional insight to application security operations based at least in part ongoing advances in cybersecurity applications. Further, the one or more security contributions 262 may be one or more commands or guidance to implement in the attack path determination engine 270. In this regard, the security expert contributors 260 may provide changes or definitions to cyberattack issues based on specific findings. These changes or definitions may comprise modifying sensitive asset inventories, or detecting and configuring additional issues or weaknesses in the application layers 122, among others.

[0054] In one or more embodiments, the attack path determination engine 270 may perform multiple operations 272-288 comprising multiple feasibility parameters 294 that are dynamically or periodically updated in accordance with the attack vector parameters 242, the security parameters 252, the security contributions 262, and the asset protection information 226. The attack path determination engine 270 may determine a current version of the feasibility parameters 294 based at least upon the attack vector parameters 242. The attack path determination engine 270 may provide the feasibility parameters 294 to an inference engine via operation 272. At the inference engine 274, the attack path determination engine 270 may be configured to determine filtering commands to be provided via the operation 282 to update the asset mapping information 178. The filtering commands may associate relevant assets 123 in one layer to vulnerable assets 123 one of the other application layers 122. The attack path determination engine 270 may be configured to determine identify, categorize, and map possible attack vectors 192 both within and across application layers 122 and provide the mapped attack vectors 192 via the operation 276 to update the asset topology 190.

[0055] In one or more embodiments, the attack path determination engine 270 may update the feasibility parameters 294 via the operation 280, the operation 282, and the operation 284 based at least in part upon the updated asset mapping information 178 and via the operation 280, the operation 276, and the operation 278 based at least upon the updated asset topology 190. At this stage, the attack path determination engine 270 may be configured to perform operations 286 and 288 with the attack path analysis engine to determine threat prioritization parameters 296 and threat remediation parameters 298 based at least in part upon the updated feasibility parameters 294 and the attack paths 155. In some embodiments, the threat prioritization parameters 296 are configured to indicate first corresponding priorities for each vulnerable asset in the first plurality of vulnerable assets or in a given attack path. In other embodiments, the threat remediation parameters 298 are configured to indicate a first solution to remediate the first attack path in the system.

[0056] In the example of FIG. **2**, the attack path determination engine **270** may be configured to determine and update the attack paths **155** to vulnerable application assets **123**. The application layers **122** may comprise an application data layer **122**A, an application logic layer **122**B, an application infrastructure layer **122**C, and an application cloud infrastructure layer **122**D.

[0057] In some embodiments, the rules and policies **176** may comprise application security solutions, and one or more trusted entities (e.g., Common Vulnerabilities and Exposures (CVEs)) among one or more additional source. The asset analysis engine **240** may further comprise a data discovery module (e.g., a managed and/or unmanaged data stores), asset classification modules, asset inventory modules, risk quantification tools (e.g., as represented in currency), and access from on-call security experts.

[0058] In the attack path determination engine **270**, the feasibility parameters **294** may be retrieved from the storage and databases **150**. In certain embodiments, the attack path analysis engine **292** may comprise the threat prioritization parameters **296** and the threat remediation parameters **298** to implement as threat prioritization and remediation actions, respectively. In certain embodiments, each of the attack vectors **192** may represent a single vulnerability or a sequence of vulnerabilities that may be exploited by a bad actor (e.g., an attacker or hacker) to gain access to one or more assets **123** in order to deliver a payload or a malicious outcome (e.g., exfiltrate data, ransomware, DoS attacks against the application, and the like). Each vulnerability may be seen as an element of a given attack vector **192**. In some embodiments, a vulnerability may be part of several attack vectors **192**. In this regard, an attack path **155** is a visual representation of a specific chain of actions or events that may occur when attack vectors **192** are exploited in a given application instance and configuration context.

[0059] In the operational flow **200** of FIG. **2**, multiple input signals to the attack path determination engine may be obtained from one or more of the collectors **124** and the scanners **126**. Each of the collectors **124** and the scanners **126** may obtain signals from assets **123**A-**123**D from each application layer of the multiple application layers **122**. Attacks may occur by exploiting vulnerabilities across these four layers. In some embodiments, the application data layer **122**A comprises the assets **123**A responsible for asset controls, classification, conformance and compliance, application modeling for anomaly detection, testing, AI/ML, and the like. In certain embodiments, the application logic layer **122**B comprises the assets **123**B responsible for API logic, serverless logic, application software, application modeling for anomaly detection, testing, AI/ML, and the like. In some embodiments, the application infrastructure layer **122**C comprises the assets **123**C responsible for Kubernetes protection, virtual machine (VM) scanning, CVEs, Common Weakness Enumerations (CWEs), serverless posture, images, Software Bill of Materials (SBOM), Secure Supply Chain (SSC), Software Licensing Supply Arrangement (SLSA), Infrastructure as code (IaC), Continuous Integration and Continuous Delivery (CICD), and the like. In certain embodiments, the application cloud infrastructure layer **122**D comprises the assets **123**D responsible for cloud security posture, agentless and full security scanning, identity and entitlement, and the like.

[0060] In one or more embodiments, the collectors **124** and the scanners **126** are centralized (e.g., deployed in the assets **123**C in the application infrastructure layer **122**C under control of an asset owner or manager)or distributed (e.g., deployed in the assets **123**D in the application cloud infrastructure layer **122**D under control of the asset owner or manager). In some embodiments, the collectors **124** and the scanners **126** support continuous or periodic scanning and/or collection capability both in active and passive mode. For example, some signals may require scanning run time environments (e.g., active mode). In another example, some may signals be collected by importing files (e.g., passive mode) or through application programming interfaces (APIs) or other means. In still another example, some signals may be obtained in various ways, such as by scanning via a plugin or collected via an upload process.

[0061] In certain embodiments, the signals are used to build the application service topology. For example, topology may be imported from the asset owner (e.g., in JSON), application security solution (e.g., Panoptica™), an Application and Performance Monitoring (APM) (e.g., Cisco AppD or Datadog™), Continuous Integration (CI) tools, and the like. In another example, signals at build time may come from IaC, API specifications, SBOM, code scanners, configs, and the like. In still another example, signals at run time may come from Cloud Infrastructure Entitlement Management (CIEM), Cloud Security Posture Management (CSPM), OpenTelemetry™, security resources engine **220** (e.g., Panoptica™), API security, container security, serverless security, virtual machine (VM) security, a human in the loop, and the like.

[0062] In some embodiments, the collectors **124** and the scanners **126** scans and/or collects signals from the application data layer **122**A, the application logic layer **122**B, the application infrastructure layer **122**C, the application cloud infrastructure layer **122**D, trusted entities (e.g., to retrieve CVEs), or other sources. Example signals that may be used to build the data topology include scanners and collectors in the data layer (e.g., connectors to a specific database, such as mongoDB or mySQL). Such signals may feed the layer statuses **214** to the asset analysis engine **240**, which in turn may feed the attack vector parameters **242** to the attack path determination engine **292**, thereby enabling the creation of asset inventory **182** for the different categories of sensitive assets handled by the applications (e.g., for PII, Payment Card Industry (PCI), confidential data, and the like).

[0063] In one or more embodiments, the attack path determination engine **270** is configured to extract example signals to generate the attack vector parameters at least in part upon the asset controls **174**, the asset discovery **180**, the asset inventory **182**, the asset classification **184**, the attack vectors **192**, and the weighted costs **194**, which depend on the type and quantity of data that might be exposed.

[0064] In one or more embodiments, an operational flow **200** comprises determining attack paths **155** to the application assets **123** and include one or more of the operations **272**-**288**. At operation **272**, the attack vector parameters **242** are used as inputs to the inference engine **274**. The inference engine **274** may be configured to generate inferences. In certain embodiments, the inference engine **274** may apply different techniques to reason on the data gathered, such as ontological knowledge, semantic relatedness, and the like.

[0065] At operation **276**, one of the techniques may comprise computation and inference of an application service topology along with a binding and/or mapping process between the data topology and the application service topol-

ogy inferred. Hence, in application service data topology, a converged topological view may be available for the application as the updated asset topology **190**. In certain embodiments, one or more different filtering techniques may be implemented in order to understand where specific categories of sensitive data sit at rest and/or asset relation flows across the application services. At operation **278**, the updated asset topology **190** is persisted in the storage and database **150**. At operation **280**, the inference engine **274** uses this topological view as a new input based at least in part upon the feasibility parameters **294**.

[0066] At operation **282**, the inference engine **274** applies another technique to identify, categorize, and/or map the possible attack vectors **192** both within and across the application layers **122**A-**122**D to the application service and/or data instance. In some embodiments, a comprehensive list of the attack vectors **192** might be known and available in advance via the memory **170** or the storage and databases **150**, so this operation may focus on identifying which of those attack vectors **192** are present in a specific app service and data instance. In some embodiments, the inference engine **274** may start from the vulnerabilities and potential intrusions found in the instance (e.g., fed to the storage and databases **150**), and then compute the possible attack vectors **192** based at least in part upon such vulnerabilities. The outcome may be compared against a set of known/common attack vectors **192**. In case of difference between the attack vectors **192** found and those that were listed and known beforehand, the list of attack vectors **192** may be updated.

[0067] At operation **284**, the list of attack vectors **192** mapped in the updated asset mapping information **178** may be persisted for the feasibility parameters **294** at the storage and databases **150**. At operation **286**, the application service and data topology along with the relevant attack vectors **192** found is used as an input by attack path analysis engine **292**. In certain embodiments, the attack path analysis engine **292** may determine whether the feasible parameters **294** indicate that the attack paths **155** comprise vulnerable assets. Such analysis may include the identification of critical threats, prioritization, and/or enumeration of detailed steps allowing remediation actions to eliminate such threats. At operation **288**, results of the attack path analysis performed by the attack path analysis engine **292** are persisted in the storage and databases **150**. In certain embodiments, the attack path determination engine may check whether any critical attack paths **155** were remediated. To dynamically determine and prioritize threats, operations **286** and **288** may run continuously or periodically, which may allow for a closed-loop analysis and remediation without requiring manual triggers of any data or application service scanning process.

[0068] FIG. **3** shows an example attack path analysis **300**, in accordance with one or more embodiments. The attack path analysis **300** may be performed by the attack path analysis engine to establish one or more threat prioritization parameters **296** or threat remediation parameters **298** for the attack paths **155**. In the example of FIG. **3**, the one or more processors **120** comprise the collectors **124** and the scanners **126** communicatively coupled to the application data layer **122**A, the application logic layer **122**B, the application infrastructure layer **122**C, and the application cloud infrastructure layer **122**D. The attack path analysis **300** may comprise identifying one or more attack vectors **192**. In the example of FIG. **3**, multiple vulnerable assets **302** are shown to include an asset **123**AA, an asset **123**AB, an asset **123**BA, an asset **123**CA, an asset **123**DA, and an asset **123**DB. The asset **123**DB is shown associated to the asset **123**DA. The asset **123**DA is shown associated to the asset **123**CA and the asset **123**AB. The asset **123**BA is shown associated with the asset **123**AA and the asset **123**AB.

[0069] In some embodiments, example attack vectors **192** comprise entry points for vulnerabilities between the asset **123**DB and the asset **123**AB; between the asset **123**DB and the asset **123**BA; between the asset **123**DB, the asset **123**BA, and the asset **123**AB; and between the asset **123**DB, the asset **123**BA, and the asset **123**AA. In the attack path analysis **300** of FIG. **3**, the application cloud infrastructure layer **122**D comprises a weak password vulnerability (e.g., breach password and privilege escalation) shown as the asset **123**DB and a role/entitlement (admin) vulnerability shown as the asset **123**DA. The application infrastructure layer **122**C may comprise a related vulnerability in, for example, a container admin command spin up command & control (C**2**) shown as the asset **123**CA. The vulnerability at the asset **123**DA may enable access to the asset **123**AB or the asset **123**CA. At the application logic layer **122**B, the vulnerabilities may comprise a CVE in a given API. The asset **123**AA and the asset **123**AB may be accessed from the asset **123**BA. In the example of FIG. **3**, the application data layer **122**A comprises unencrypted PII in MongoDB as a vulnerability shown in the asset **123**AA and an unencrypted PCI in S**3** bucket as a vulnerability shown in the asset **123**AB. This example may be used by the attack path analysis engine **292** to compute attack paths **155** and remediation actions for these attack paths **155**. As described above, an attack path **155** may comprise multiple segments. In other embodiments, a first attack path may be from the asset **123**DB to the asset **123**AB via the asset **123**DA; a second attack path may be from the asset **123**DB to the asset **123**AA via the asset **123**DA and the asset **123**BA; and a third attack path may be from the asset **123**DB to the asset **123**AB via the asset **123**DA and the asset **123**BA.

[0070] In one or more embodiments, as part of the attack path analysis **300**, the one or more processors **120** implementing the attack path analysis engine **292** may be configured to assign weighted costs **194** to any visual representation of the vulnerable assets **302** (e.g., to the edges). Each weighted cost **194** may comprise a difficulty to transition between any two assets **123** and a risk-cost associated with the impact of bad actors accessing a given asset in the application layers **122**. For example, to model the difficulty for an attacker to make a transition between two nodes in the graph (e.g., to successfully carry out the action represented by the edge). In this regard, the attack path analysis **300** may comprise determining whether the attack vectors **192** are feasible as vulnerable entry points into the application layers **122** and are labeled for computing the least resistant attack path to reach the data asset. For instance, a node representing the action "C**2** starts with App" may require an attacker to first get C**2** into the application code. Hence, not every asset is a feasible source for attack path computation.

[0071] There are novel elements to this since this goes beyond reducing false positives. For instance, it considers whether a source node in a DAG is a feasible starting point for an attack path and may discard it as a source and/or augment dynamically the graph as needed to cover this. For instance, a command & control (C**2**) instance cannot be the

source of an attack path, since an attacker would first need other means (e.g., poison the code, the CICD pipeline, etc.) to spin up C2.

[0072] In one or more embodiments, the attack path analysis **300** computes minimum cost paths for each attackable data asset from every feasible source node in the graph. In certain embodiments, the attack path analysis **300** comprises selecting a least resistant (e.g., minimum cost) attack path **155** to breach unencrypted PCI in a managed S3 bucket. At this stage, the attack path analysis **300** comprises prioritizing threats and enumerating any required remediation actions, persist existing the results, of ending the analysis. In the example of FIG. **3**, weighted costs **310**-**340** are shown as different costs associated with vulnerability accesses from one asset to another. For example, a first path from the asset **123**DB to the asset **123**DA comprises the weighted cost **350**, a second path from the asset **123**DA to the asset **123**AB comprises the weighted cost **340**, a third path from the asset **123**DA to the asset **123**CA comprises the weighted cost **330**, a fourth path from the asset **123**CA to the asset **123**BA comprises the weighted cost **320**, a fifth path from the asset **123**BA to the asset **123**AA comprises the weighted cost **310**, and a sixth path from the asset **123**BA to the asset **123**AB also comprises the weighted cost **310**.

[0073] FIG. **4** shows an example flowcharts of a process to determine attack paths to application assets associated with one or more application layers in a multi-layer application, in accordance with one or more embodiments. Modifications, additions, or omissions may be made to the process **400**. The process **400** may include more, fewer, or other operations than those shown below. For example, operations may be performed in parallel or in any suitable order. While at times discussed as the network component **102**, the one or more processors **120**, or components of any of thereof, any suitable system or components of the system **100** may perform one or more operations of the process **400**. For example, one or more operations of process **400** may be implemented, at least in part, in the form of software instructions **172** of FIG. **1**, stored on non-transitory, tangible, machine-readable media (e.g., memory **170** of FIG. **1**) that when run by one or more processors (e.g., one or more processors **120** of FIG. **1**) may cause the one or more processors to perform operations described in operations **402**-**430**.

[0074] The process **400** starts at operation **402**, where the one or more processors **120** obtain current attack vectors **192** from the storage and databases **150**. The process **400** continues at operation **410**, where the one or more processors **120** determine whether the attack vectors **192** comprise any updates. If the attack vectors **192** do not comprise any updates (e.g., NO), the process **400** continues to operation **430**. If the attack vectors **192** comprise one or more updates (e.g., YES), the process **400** proceeds to operation **412**. At operation **412**, the one or more processors **120** determine vulnerable assets from the current attack vectors **192**. At operation **414**, the one or more processors **120** generate a visualization interface. At operation **416**, the one or more processors **120** present the visualization interface in a display or other I/O interface **130**.

[0075] As shown in the visualization **450**, a PII **440** and a PCI **444** are identified as target assets **123** vulnerable via one or more attack paths **155**. Following as a non-limiting example of the discussion of FIG. **3**, the asset **123**DB may be a starting point for attack paths **155** reaching to the PII **440** and the PCI **444**. The attack paths **155** may proceed to the asset **123**BA or the asset **123**AB. Further, from the asset **123**BA. The attack paths may further branch out to asset **123**AA and the asset **123**AB. From the asset **123**AA, one of the attack paths **155** may reach the PII **440**. From the asset **123**AB, another of the attack paths **155** may reach the PCI **444**. The visualization **450** may be a directed acyclic graph (DAG) that is updated dynamically or periodically over time.

[0076] The process **400** continues at operation **418**, where the one or more processors **120** determine the one or more attack paths **155**. At operation **420**, the one or more processors **120** update the visualization interface. At operation **422**, the one or more processors **120** assign weighted costs **194** to transitions between any two vulnerable assets **123** in the attack paths **155**. For example, at operation **422**, the process **400** assigns weighted costs **194** to the edges of the DAG At operation **424**, the one or more processors **120** determine the feasibility for each of the vulnerable assets **123** based at least in part upon the updated feasibility parameters **294** as updated by the attack path determination engine **270**. At operation **426**, the one or more processors **120** calculate the weighted costs **194** for transitions between any two assets **123** in multiple attack paths **155**. For example, at operation **426**, the process **400** determines total weighted costs **194** for each attack path **155** identified in the DAG. At operation **428**, the one or more processors **120** prioritize threats and enumerate remediation actions for each of the attack paths **155**.

[0077] As shown in the visualization **452**, attack paths **155** from the asset **123**DB to the PII **440** or the PCI **444** may be assigned different intermediate vulnerable assets **123** in accordance with the one or more feasibility parameters **294** (e.g., shown as a first feasibility parameter **294**A and a second feasibility parameter **294**B. Further, in the visualization **452**, the feasibility parameters **294** are replaced with one or more vulnerable assets that make the attack paths **155** feasible. In the case of the visualization **452**, the asset **123**DA and the asset **123**CA provide a first feasible attack path **155** from the asset **123**DB to the PII **440** and the PCI **444**. Further, the asset **123**DA provides a second feasible attack path **155** from the asset **123**DB to the PCI **444**. In addition, the size of the PII **440** and the size of the PCI **444** are modified in accordance with one or more corresponding weighted costs **194** (e.g., based on the volume of sensitive assets exposed or the priority of the category of assets at risk). In this regard, the PII **440** is smaller than the PCI **444**, which may indicate that a volume of the PCI **444** data is more greater than a volume of the PII **440** data exposed or may indicate that the PII **440** is more relevant to the application layers **122** than the PII **440**. To this end, the attack path determination engine **270** may prioritize remediation of the vulnerabilities in the attack path that enables attack vectors **192** to reach the PCI **444**.

[0078] The process **400** ends at operation **430**, where the one or more processors **120** provide results to the storage and databases **150**. As shown in visualization **454**, the results may comprise selecting an attack path **155** to reach the PCI **444** as the attack path **155** to remediate.

[0079] Herein, "or" is inclusive and not exclusive, unless expressly indicated otherwise or indicated otherwise by context. Therefore, herein, "A or B" means "A, B, or both," unless expressly indicated otherwise or indicated otherwise by context. Moreover, "and" is both joint and several, unless

expressly indicated otherwise or indicated otherwise by context. Therefore, herein, "A and B" means "A and B, jointly or severally," unless expressly indicated otherwise or indicated otherwise by context.

[0080] The scope of this disclosure encompasses all changes, substitutions, variations, alterations, and modifications to the example embodiments described or illustrated herein that a person having ordinary skill in the art would comprehend. The scope of this disclosure is not limited to the example embodiments described or illustrated herein. Moreover, although this disclosure describes and illustrates respective embodiments herein as including particular components, elements, feature, functions, operations, or steps, any of these embodiments may include any combination or permutation of any of the components, elements, features, functions, operations, or steps described or illustrated anywhere herein that a person having ordinary skill in the art would comprehend. Additionally, although this disclosure describes or illustrates particular embodiments as providing particular advantages, particular embodiments may provide none, some, or all of these advantages.

[0081] The embodiments disclosed herein are only examples, and the scope of this disclosure is not limited to them. Particular embodiments may include all, some, or none of the components, elements, features, functions, operations, or steps of the embodiments disclosed herein.

[0082] Modifications, additions, or omissions may be made to the elements shown in the figures above. The components of a device may be integrated or separated. Moreover, the functionality of a device may be performed by more, fewer, or other components. The components within a device may be communicatively coupled in any suitable manner. Functionality described herein may be performed by one device or distributed across multiple devices. In general, systems and/or components described in this disclosure as performing certain functionality may comprise non-transitory computer readable memory storing instructions and processing circuitry operable to execute the instructions to cause the system/component to perform the described functionality.

[0083] While several embodiments have been provided in the present disclosure, it should be understood that the disclosed systems and methods might be embodied in many other specific forms without departing from the scope of the present disclosure. The present examples are to be considered as illustrative and not restrictive, and the intention is not to be limited to the details given herein. For example, the various elements or components may be combined or integrated in another system or certain features may be omitted, or not implemented.

[0084] In addition, techniques, systems, subsystems, and methods described and illustrated in the various embodiments as discrete or separate may be combined or integrated with other systems, modules, techniques, or methods without departing from the scope of the present disclosure. Other items shown or discussed as coupled or directly coupled or communicating with each other may be indirectly coupled or communicating through some interface, device, or intermediate component whether electrically, mechanically, or otherwise. Other examples of changes, substitutions, and alterations are ascertainable by one skilled in the art and could be made without departing from the spirit and scope disclosed herein.

[0085] Any appropriate steps, methods, features, functions, or benefits disclosed herein may be performed through one or more functional units or modules of one or more virtual apparatuses. Each virtual apparatus may comprise a number of these functional units. These functional units may be implemented via processing circuitry configured to execute program code stored in memory. The term unit may have conventional meaning in the field of electronics, electrical devices and/or electronic devices and may include, for example, electrical and/or electronic circuitry, devices, modules, processors, receivers, transmitters, memories, logic solid state and/or discrete devices, computer programs or instructions for carrying out respective tasks, procedures, computations, outputs, and/or displaying functions, and so on, as such as those that are described herein.

1. A system, comprising:

a memory configured to store:

asset inventory indicating a plurality of application assets;

a first plurality of attack vector parameters configured to indicate vulnerabilities of one or more of the plurality of application assets; and

asset mapping information configured to associate each of the plurality of application assets to one or more of a plurality of application layers, the plurality of application layers comprising an application data layer, an application logic layer, an application infrastructure layer, and an application cloud infrastructure layer; and

a processor communicatively coupled to the memory and configured to:

determine a first plurality of vulnerable assets in the plurality of application assets based at least in part upon the first plurality of attack vector parameters;

determine a first plurality of feasibility parameters that indicate a first likelihood of a first attack path to occur in the system;

generate a visual interface showing the first plurality of vulnerable assets;

determine the first attack path connecting the first plurality of vulnerable assets based at least in part upon the asset mapping information; and

map the first attack path to the plurality of application layers in the visual interface based at least in part upon the first plurality of feasibility parameters.

2. The system of claim **1**, wherein:

the first plurality of feasibility parameters further indicate a first starting point of the first attack path.

3. The system of claim **2**, wherein the processor is further configured to:

obtain a second plurality of attack vector parameters;

determine a second plurality of vulnerable assets in the plurality of application assets based at least in part upon the second plurality of attack vector parameters;

generate the visual interface showing the first plurality of vulnerable assets and the second plurality of vulnerable assets;

determine a second attack path connecting the second plurality of vulnerable assets based at least in part upon the asset mapping information;

determine a second plurality of feasibility parameters that indicate a second likelihood of the second attack path to occur in the system, the second plurality of feasibil-

ity parameters further indicate a second starting point of the second attack path; and

map the second attack path to the plurality of application layers in the visual interface based at least in part upon the second plurality of feasibility parameters.

4. The system of claim **3**, wherein the processor is further configured to:

in conjunction with determining the first plurality of vulnerable assets, determine a first weighted cost to compromise the first plurality of vulnerable assets from the first attack path;

in conjunction with determining the second plurality of vulnerable assets, determine a second weighted cost to compromise the second plurality of vulnerable assets from the second attack path;

determine whether the first weighted cost is greater than the second weighted cost;

in response to determining that the first weighted cost is greater than the second weighted cost, prioritize remediation for the second attack path; and

in response to determining that the second weighted cost is greater than the first weighted cost, prioritize remediation for the first attack path.

5. The system of claim **4**, wherein the processor is further configured to:

in response to the second weighted cost being greater than the first weighted cost, generate a first plurality of threat prioritization parameters that indicate first corresponding priorities for each vulnerable asset in the first plurality of vulnerable assets;

generate a first plurality of remediation parameters that indicate a first solution to remediate the first attack path in the system;

assign the first plurality of threat prioritization parameters and the first plurality of remediation parameters to the first attack path in the visual interface;

in response to the first weighted cost being greater than the second weighted cost, generate a second plurality of threat prioritization parameters that indicate second corresponding priorities for each vulnerable asset in the second plurality of vulnerable assets;

generate a second plurality of remediation parameters that indicate a second solution to remediate the second attack path in the system; and

assign the second plurality of threat prioritization parameters and the second plurality of remediation parameters to the second attack path in the visual interface.

6. The system of claim **1**, wherein:

the first plurality of attack vector parameters comprise a comprehensive list of attack vectors.

7. The system of claim **1**, wherein:

the first plurality of attack vector parameters comprise information indicating the vulnerabilities and potential intrusions in the plurality of application layers.

8. A method, comprising:

obtaining a plurality of parameters, comprising:

asset inventory indicating a plurality of application assets;

a first plurality of attack vector parameters configured to indicate vulnerabilities of one or more of the plurality of application assets; and

asset mapping information configured to associate each of the plurality of application assets to one or more of a plurality of application layers, the plurality of application layers comprising an application data layer, an application logic layer, an application infrastructure layer, and an application cloud infrastructure layer;

determining a first plurality of vulnerable assets in the plurality of application assets based at least in part upon the first plurality of attack vector parameters;

determining a first plurality of feasibility parameters that indicate a first likelihood of a first attack path to occur in a system;

generating a visual interface showing the first plurality of vulnerable assets;

determining the first attack path connecting the first plurality of vulnerable assets based at least in part upon the asset mapping information; and

mapping the first attack path to the plurality of application layers in the visual interface based at least in part upon the first plurality of feasibility parameters.

9. The method of claim **8**, wherein:

the first plurality of feasibility parameters further indicate a first starting point of the first attack path.

10. The method of claim **9**, further comprising:

obtaining a second plurality of attack vector parameters;

determining a second plurality of vulnerable assets in the plurality of application assets based at least in part upon the second plurality of attack vector parameters;

generating the visual interface showing the first plurality of vulnerable assets and the second plurality of vulnerable assets;

determining a second attack path connecting the second plurality of vulnerable assets based at least in part upon the asset mapping information;

determining a second plurality of feasibility parameters that indicate a second likelihood of the second attack path to occur in the system, the second plurality of feasibility parameters further indicate a second starting point of the second attack path; and

mapping the second attack path to the plurality of application layers in the visual interface based at least in part upon the second plurality of feasibility parameters.

11. The method of claim **10**, further comprising:

in conjunction with determining the first plurality of vulnerable assets, determining a first weighted cost to compromise the first plurality of vulnerable assets from the first attack path;

in conjunction with determining the second plurality of vulnerable assets, determining a second weighted cost to compromise the second plurality of vulnerable assets from the second attack path;

determining whether the first weighted cost is greater than the second weighted cost;

in response to determining that the first weighted cost is greater than the second weighted cost, prioritizing remediation for the second attack path; and

in response to determining that the second weighted cost is greater than the first weighted cost, prioritizing remediation for the first attack path.

12. The method of claim **11**, further comprising:

in response to the second weighted cost being greater than first weighted cost, generating a first plurality of threat prioritization parameters that indicate first corresponding priorities for each vulnerable asset in the first plurality of vulnerable assets;

generating a first plurality of remediation parameters that indicate a first solution to remediate the first attack path in the system;

in response to the first weighted cost being greater than the second weighted cost, generating a second plurality of threat prioritization parameters that indicate second corresponding priorities for each vulnerable asset in the second plurality of vulnerable assets;

generating a second plurality of remediation parameters that indicate a second solution to remediate the second attack path in the system; and

assigning the second plurality of threat prioritization parameters and the second plurality of remediation parameters to the second attack path in the visual interface.

13. The method of claim **8**, wherein:

the first plurality of attack vector parameters comprise a comprehensive list of attack vectors.

14. The method of claim **8**, wherein:

the first plurality of attack vector parameters comprise information indicating the vulnerabilities and potential intrusions in the plurality of application layers.

15. A non-transitory computer readable medium storing instructions that when executed by a processor cause the processor to:

obtain a plurality of parameters, comprising:

asset inventory indicating a plurality of application assets;

a first plurality of attack vector parameters configured to indicate vulnerabilities of one or more of the plurality of application assets; and

asset mapping information configured to associate each of the plurality of application assets to one or more of a plurality of application layers, the plurality of application layers comprising an application data layer, an application logic layer, an application infrastructure layer, and an application cloud infrastructure layer;

determine a first plurality of vulnerable assets in the plurality of application assets based at least in part upon the first plurality of attack vector parameters;

determine a first plurality of feasibility parameters that indicate a first likelihood of a first attack path to occur in a system;

generate a visual interface showing the first plurality of vulnerable assets;

determine the first attack path connecting the first plurality of vulnerable assets based at least in part upon the asset mapping information; and

map the first attack path to the plurality of application layers in the visual interface based at least in part upon the first plurality of feasibility parameters.

16. The non-transitory computer readable medium of claim **15**, wherein:

the first plurality of feasibility parameters further indicate a first starting point of the first attack path.

17. The non-transitory computer readable medium of claim **16**, wherein the instructions further cause the processor to:

obtain a second plurality of attack vector parameters;

determine a second plurality of vulnerable assets in the plurality of application assets based at least in part upon the second plurality of attack vector parameters;

generate the visual interface showing the first plurality of vulnerable assets and the second plurality of vulnerable assets;

determine a second attack path connecting the second plurality of vulnerable assets based at least in part upon the asset mapping information;

determine a second plurality of feasibility parameters that indicate a second likelihood of the second attack path to occur in the system, the second plurality of feasibility parameters further indicate a second starting point of the second attack path; and

map the second attack path to the plurality of application layers in the visual interface based at least in part upon the second plurality of feasibility parameters.

18. The non-transitory computer readable medium of claim **17**, wherein the instructions further cause the processor to:

in conjunction with determining the first plurality of vulnerable assets, determine a first weighted cost to compromise the first plurality of vulnerable assets from the first attack path;

in conjunction with determining the second plurality of vulnerable assets, determine a second weighted cost to compromise the second plurality of vulnerable assets from the second attack path;

determine whether the first weighted cost is greater than the second weighted cost;

in response to determining that the first weighted cost is greater than the second weighted cost, prioritize remediation for the second attack path; and

in response to determining that the second weighted cost is greater than the first weighted cost, prioritize remediation for the first attack path.

19. The non-transitory computer readable medium of claim **18**, wherein the instructions further cause the processor to:

in response to the second weighted cost being greater than the first weighted cost, generate a first plurality of threat prioritization parameters that indicate first corresponding priorities for each vulnerable asset in the first plurality of vulnerable assets;

generate a first plurality of remediation parameters that indicate a first solution to remediate the first attack path in the system;

in response to the first weighted cost being greater than the second weighted cost, generate a second plurality of threat prioritization parameters that indicate second corresponding priorities for each vulnerable asset in the second plurality of vulnerable assets;

generate a second plurality of remediation parameters that indicate a second solution to remediate the second attack path in the system; and

assign the second plurality of threat prioritization parameters and the second plurality of remediation parameters to the second attack path in the visual interface.

20. The non-transitory computer readable medium of claim **15**, wherein:

the first plurality of attack vector parameters comprise information indicating the vulnerabilities and potential intrusions in the plurality of application layers.

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