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### SYSTEM FOR IDENTIFYING POINTS OF COMPROMISE

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#### Abstract

The disclosure describes an apparatus having programmed instructions that when executed cause the apparatus to receive, via a communication network, information regarding suspicious fraud activity at a first location involving a plurality of transaction cards; monitor changes over a first time interval to received information regarding suspicious fraud activity at the first location; and identify a point-of-compromise (POC) location based on monitored changes surpassing a threshold indicating suspicious fraud activity at the first location over the first time interval.

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## Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is Continuation of and claims the benefit of priority to U.S. patent application Ser. No. 18/441,260, filed Feb. 14, 2024, which claims the benefit of priority as a Continuation of U.S. patent application Ser. No. 17/082,664 filed Oct. 28, 2020, which claims the benefit of priority as a Continuation-In-Part of U.S. Non-Provisional patent application Ser. No. 16/562,724, filed Sep. 6, 2019, the entirety of each of which is incorporated by reference herein.

### BACKGROUND

[0002] The following description is provided to assist the understanding of the reader. None of the information provided or references cited is admitted to be prior art.

[0003] Credit and debit cards play a major role in financial transactions throughout the world. However, traditional credit and debit cards struggle with a number of drawbacks. For example, the magnetic stripe information can be compromised by a skimmer device placed in a point-of-sale location or card information can be stolen using a malware breach in a merchant's system. Compromised cards can then be used for fraudulent transactions. Failure to timely detect a point of compromise where card information is illegitimately obtained can result in more and more cards being used for fraud. Such activity causes significant business loss to card issuers. Furthermore, such fraud damages the trust and relationships between card issuers and customers.

[0004] Heretofore, attempts have been made to identify points of compromise in the financial card network using computer systems but such systems have not succeeded to quickly identify locations where card information is compromised and fraudulently used.

### SUMMARY

[0005] In accordance with some aspects of the present disclosure, a system is disclosed to identify points of compromise using monitoring and analysis of interactions between the fraud cards and the points of sale. For purposes of this description, a fraud card is any credit and/or debit card including personal, business, and corporate, that had at least one known or suspicious fraud transaction within a certain time period, such as six months. The time window of the recent transactions is adjustable, depending on factors including the number of transactions, the risks of potential points-of-compromise, etc. The system selects a time window of recent transactions from which it cumulates fresh fraud transactions to monitor and detect any possible points-of-compromise.

[0006] In accordance with some aspects of the present disclosure, an apparatus includes programmed instructions that when executed cause the apparatus to receive, via a communication network, information regarding suspicious fraud activity at a first location involving a plurality of transaction cards; monitor changes over a first time interval to received information regarding suspicious fraud activity at the first location; and identify a point-of-compromise (POC) location based on monitored changes surpassing a threshold indicating suspicious fraud activity at the first location over the first time interval.

[0007] The received fraud transaction information can be arranged in a first two-dimensional matrix at a first time interval and in a second two-dimensional matrix at a second time interval. The apparatus can then determine from comparing data in the first two-dimensional matrix and the second two-dimensional matrix a point of compromise (POC) indicator, a POC acceleration indicator, and a card fraud acceleration indicator. The apparatus can then use these indicators to

present a candidate POC location.

[0008] In accordance with some other aspects of the present disclosure, a computerized method is disclosed. The method includes collecting location data for suspicious fraud transactions involving a plurality of transaction cards over a first time window; repeating the collecting operations over additional time windows; constructing a three-dimensional matrix using collected locations, associated transaction cards, and time windows; updating the three-dimensional matrix after each new time window; and generating from the three-dimensional matrix at each update a candidate point-of-compromise (POC) location.

[0009] In accordance with yet other aspects of the present disclosure, a non-transitory computer readable media with computer-executable instructions embodied thereon is disclosed. The instructions when executed by a processor of a system cause a system to perform a process. The process includes collecting location data for suspicious fraud transactions over a first time window; collecting location data for non-fraud transactions over the first time window; repeating the collecting operations over additional time windows; constructing a three-dimensional matrix using collected locations, associated transaction cards, and time windows; updating the three-dimensional matrix after each new time window; and generating from the three-dimensional matrix at each update a point-of-compromise (POC) indicator, a POC acceleration indicator, and a card fraud acceleration indicator.

[0010] The foregoing summary is illustrative only and is not intended to be in any way limiting. In addition to the illustrative aspects, embodiments, and features described above, further aspects, embodiments, and features will become apparent by reference to the following drawings and the detailed description.

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## Description

### BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 is an example block diagram of a networked transaction system in accordance with some embodiments of the present disclosure.

[0012] FIG. 2 is an example block diagram of a networked transaction system with some points of sale being compromised, in accordance with some embodiments of the present disclosure.

[0013] FIG. 3 is an example block diagram of a point-of-compromise detection system, in accordance with some embodiments of the present disclosure.

[0014] FIG. 4 is an example flow diagram outlining a process for point-of-compromise detection in accordance with some embodiments of the present disclosure.

[0015] FIG. 5A is a reference matrix of transaction cards and locations for a particular time interval in accordance with some embodiments of the present disclosure.

[0016] FIG. 5B is a newly generated matrix for a subsequent time period after the time period shown in FIG. 5A where additional transactions occurred, but no new fraudulent transactions occurred.

[0017] FIG. 5C is a newly generated matrix for yet another subsequent time period after the time period shown in FIG. 5A where new fraudulent transactions occurred at locations where fraudulent transactions have occurred before.

[0018] FIG. 5D is a newly generated matrix for another subsequent time period after the time period shown in FIG. 5A where new fraudulent transactions for a specific card/location pair occurred, but there had previously been fraudulent transactions on that card and at that location.

[0019] FIG. 5E is a newly generated matrix for a subsequent time period after the time period shown in FIG. 5A where new fraudulent transactions occurred at a new location, but no new cards had fraudulent transactions.

[0020] FIG. 5F is a newly generated matrix for a subsequent time period after the time period

shown in FIG. 5A where new fraudulent transactions occurred on new cards, but at locations that had previous fraudulent transactions.

[0021] FIGS. 6A-6C show multiple matrices from several subsequent time intervals which are used to generate point-of-compromise indicators, point-of-compromise acceleration indicators, and card fraud indicators.

[0022] FIG. 7A depicts an example card fraud indicator (CFI) trend table.

[0023] FIG. 7B depicts an example POC (points-of-compromise) & POC acceleration indicator (PAI) trend table.

[0024] FIG. 8A depicts an example mass count plot.

[0025] FIG. 8B depicts an example sub-list associated with the mass count plot.

[0026] FIG. 8C depicts an example sub-list associated with the mass count plot.

[0027] FIG. 8D depicts an example mass count plot.

[0028] FIG. 9A is an example area under the curve (AUC) plot of a training set.

[0029] FIG. 9B is an example AUC plot of a testing set.

[0030] FIG. 10 is an example diagram of a memory device.

[0031] FIG. 11 is an example circuit diagram of the memory cell.

[0032] FIG. 12 is an example block diagram of a computing system.

[0033] The foregoing and other features of the present disclosure will become apparent from the following description and appended claims, taken in conjunction with the accompanying drawings. Understanding that these drawings depict only several embodiments in accordance with the disclosure and are, therefore, not to be considered limiting of its scope, the disclosure will be described with additional specificity and detail through use of the accompanying drawings.

#### DETAILED DESCRIPTION

[0034] In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, drawings, and claims are not meant to be limiting. Other embodiments may be utilized, and other changes may be made, without departing from the spirit or scope of the subject matter presented here. It will be readily understood that the aspects of the present disclosure, as generally described herein, and illustrated in the figures, can be arranged, substituted, combined, and designed in a wide variety of different configurations, all of which are explicitly contemplated and make part of this disclosure.

[0035] The present disclosure is generally directed to a real-time point-of-compromise detection system having a point-of-compromise detection server in communication with points-of-sale devices through a network. The communication between the point-of-compromise detection server and the points-of-sale devices may be facilitated through an exchange application located at the point-of-sale device and on the point-of-compromise detection server. A variety of management and non-management related operations may be performed on the point-of-compromise detection system.

[0036] Exemplary embodiments described herein provide a point-of-compromise detection system that can automatically determine which points-of-sale devices and cards may be possible points-of-compromise. These points-of-compromise could have malware or physical devices that steal the magnetic stripe information from bank cards. Detecting these problematic point-of-sale locations can lead to investigation and repair of the point-of-sale. Similarly, bank cards such as credit or debit cards can be determined to be compromised. These compromised cards can be deactivated or de-authorized in order to prevent future fraudulent transactions. More specifically, the point-of-compromise detection system can use data analysis over intervals of time to determine which locations and cards are likely points-of-compromise, decreasing fraudulent transactions.

[0037] According to an exemplary embodiment, the point-of-compromise detection system can identify points-of-compromise, whether the points-of-compromise are compromised points-of-sale

devices or compromised bank cards. The point-of-compromise detection system can determine which point-of-sale locations may have a card skimmer or a malware problem that is stealing card magnetic strip information. The point-of-compromise detection system can generate indicators based on the frequency of fraudulent transactions and the total number of transactions over specific time intervals. One indicator is the POC indicator which is helpful for identifying POCs with fewer total card transactions. Additionally, POC indicators are updated when the card is used in a fraudulent or suspicious transaction at another location. That way POC indicators can also be used to find POCs even when the card is not frequently used at the same location.

[0038] Advantageously, the present disclosure describes a system that can also use POC acceleration indicators. POC acceleration indicators are able to determine POCs that involve larger number of card transactions. POC acceleration indicators help identify when the number of fraudulent cards per time interval used at the location increases over time.

[0039] Beneficially, the present disclosure describes a system that can determine a specific time window when the compromise event took place. The system can use at least one of a mass count list or a mass count plot to detect a time window when the compromise event took place. By detecting the time window, the system can detect potential compromised cards, which had transactions at the point of compromise and in the same time window. Therefore, the cards that had transactions at the point of compromise but outside of the compromise time window can be treated as normal, not a victim of the compromise event.

[0040] Advantageously, the present disclosure describes a system that can determine a reissue score for the compromised cards based on the severity level of the compromise event and the transaction characteristics of the cards. The proposed reissue score helps the card issuer make decisions of whether a compromised card needs to be reissued in the coming monitoring windows.

[0041] Beneficially, the present disclosure describes a system that can be implemented using memory arrays such as static random access memory (SRAM) arrays. In order to provide real-time detection of compromised cards, the system needs to be supported with low-latency technology. To prevent the storage element from being the bottleneck of the system, the two- and/or three-dimensional matrices that store information regarding suspicious fraud activity at various locations and/or time intervals can be implemented using SRAM arrays. Moreover, data can be tiered between faster storage technology and slower storage technology to balance the need for real-time analysis and big data storage capacity.

[0042] The present disclosure describes the technical challenges and the technical solutions associated with point-of-compromise detection systems. The embodiments described herein enable a scalable solution that detects points-of-compromise locations using time intervals and changes in frequency of detected suspicious activity. The embodiments result in a system that is much faster in identifying points-of-compromise locations than prior systems. The system can be updated and tuned to specific volumes of transactions at a location. The system can also be linked to particular merchants to identify points-of-compromise locations linked to a common merchant.

[0043] FIG. 1 illustrates a point-of-compromise detection system **100** that includes transaction cards **101**, **102**, **103**; points-of-sale devices **111**, **112**, **113**; network **120**, and a point-of-compromise detection server **130**. Each point-of-sale device **111**, **112**, **113** and the point-of-compromise detection server **130** may be coupled to network **120** through a network interface. Each of elements **111**, **112**, **113**, **120**, and **130** may be implemented or associated with hardware components, software components, or firmware components or any combination of such components. The point-of-compromise detection server **130** includes a memory or database **140** to store information received regarding the point-of-sale devices. The database **140** stores matrices **150** including matrix **151**, matrix **152**, matrix **153**, etc. that contain data regarding transaction cards **101**, **102**, and **103** and points-of-sale devices **111**, **112**, and **113** as discussed in more detail below.

[0044] The point-of-compromise detection system **100** enables the detection of compromised transaction cards and/or compromised point-of-sale device locations using programmed

instructions stored at the point-of-compromise detection server **130** that cause the point-of-compromise detection server **130** to analyze data received from the points-of-sale devices **111**, **112**, and **113** at multiple time intervals. Each matrix **151**, **152**, and **153** stores data regarding transaction cards and point-of-sale device locations over a different time interval. The point-of-compromise detection server **130** processes the matrices to identify points-of compromise in the point-of-compromise detection system **100**, as described in more detail below.

[0045] FIG. 2 illustrates a point-of-compromise detection system **200** that includes points-of-sale devices **211**, **212**, and **213**; network **220**, and a point-of-compromise detection server **230**. The point-of-compromise detection server **230** includes a memory or database **240** to store information received regarding the point-of-sale devices in matrices **250** including matrix **251**, matrix **252**, matrix **253**, etc. The point-of-compromise detection server **230** processes data received from the points-of-sale devices **211**, **212**, and **213** and determines possible points-of compromise at point-of-sale (POS) device **211** and POS device **213**. The point-of compromise at POS device **211** can be a skimmer device **260** that reads the magnetic strip information of transaction cards presented at the POS device **211** and transmits the information to a bad actor. The point-of-compromise at POS device **213** can be malware software **270** installed on the POS device **213** that captures account information from a transaction card and transmits the information to a bad actor. Other types of devices and software besides skimmer devices and malware may be used at points-of-sale devices to compromise transaction information.

[0046] FIG. 3 illustrates a point-of-compromise detection system **300** that includes transaction cards **301**, **302**, **303**, and **304**; points-of-sale devices **311**, **312**, and **313**; network **320**, and a point-of-compromise detection server **330**. The point-of-compromise detection server **330** includes a memory or database **340** to store information received regarding the point-of-sale devices. In an example embodiment, the database **340** stores matrices **350** including matrix **351**, matrix **352**, matrix **353**, etc. that contain data regarding transaction cards **301**, **302**, **303**, and **304** and points-of-sale devices **311**, **312**, and **313**. The point-of-compromise detection server **330** processes data received from the points-of-sale devices **311**, **312**, and **313** and determines possible points-of compromise at point-of-sale (POS) device **311** and POS device **313**. The information processed by the point-of-compromise detection server **330** determines that cards **301** and **304** are compromised and the point-of-compromise detection server **330** can send alerts to card issuers regarding the determination of compromise for each card. The issuer can terminate authorization and/or take additional steps to remedy the compromised cards.

[0047] FIG. 4 illustrates an exemplary flowchart outlining the generation of a new two dimensional matrix for locations and cards for a particular time interval in accordance with some embodiments of the present disclosure. Additional, fewer, or different operations may be performed in the method depending on the implementation and arrangement. The method **400** conducted by a data processing system (e.g. point-of-compromise detection server **130**, shown and described with reference to FIG. 1) includes determining if there are new fraudulent activities during the time interval (**410**), identifying whether new cards have fraudulent or suspicious activity (**420**), adding new cards/rows to a card-location matrix (**422**), assessing if new locations have fraudulent or suspicious activity (**430**), adding new locations/columns to the card-location matrix (**432**), incrementing non-zero values for cards that had new fraudulent activity (**440**), setting all new location/card fraud pairs to 1 (**450**), and updating total cards transactions at location (**460**).

[0048] The point-of-compromise detection system generates a new two dimensional matrix for a time interval which is copy of a two dimensional matrix for the previous time interval. The copy serves as the basis for the two dimensional matrix generated for the time interval that just transpired and is updated with collected data for the time interval that just transpired.

[0049] At operation **410**, the point-of-compromise detection system determines if there have been any new fraudulent or suspicious activity. If the point-of-compromise detection system determines that there were no new fraudulent transactions, then only the total card transactions need to be

updated at locations which have had previous fraudulent or suspicious activity. If the point-of-compromise detection system determines that there has been new fraudulent or suspicious activity, then the system determines where these new fraudulent or suspicious activity occurred in order to generate the new two dimensional matrix for the time interval that just transpired.

[0050] At operation **420**, the point-of-compromise detection system determines if there have been new cards involved with new fraudulent or suspicious activity. If the point-of-compromise detection system determines that new cards were involved with new fraudulent or suspicious behavior, the point-of-compromise system, at operation **422**, adds these new cards as rows to the matrix. Otherwise, no new cards or rows will be added to the matrix.

[0051] At operation **430**, the point-of-compromise detection system determines if there have been new locations involved with new fraudulent or suspicious activity. If the point-of-compromise detection system determines that new locations were involved with new fraudulent or suspicious behavior, the point-of-compromise detection system, at operation **432**, adds these new locations as columns to the matrix. Otherwise, no new locations or columns will be added to the matrix.

[0052] At operation **440**, the point-of-compromise detection system increments non-zero values for cards that had new fraudulent or suspicious activity during the time interval that just transpired. This increment affects all of the POC indicators and POC acceleration indicators relating to all locations for that particular card. This change represents that the card is still engaging in fraudulent and suspicious activity and may have been compromised at one of the previous locations.

[0053] At operation **450**, the point-of-compromise detection system sets all new location/card pairs to 1. These values are used to determine the POC indicators and POC acceleration indicators relating to all new locations for that particular card.

[0054] At operation **460**, the point-of-compromise detection system updates the total cards used at location to be the total of the previous time interval's matrix added to the total new cards that have engaged in transactions at each location.

[0055] The method depicted in FIG. **4** can also be used to update an existing two dimensional matrix for locations and cards for a particular time interval, in accordance with some embodiments of the present disclosure. The operations for updating an existing two dimensional matrix are similar to generating a new two-dimensional matrix as described previously. The only difference is that the updated matrix for the time interval that just transpired will replace the previous matrix. In such circumstances, the point-of-compromise detection server stores previous POC indicators and POC acceleration indicators for each location. Similarly, the point-of-compromise detection server may store previous card fraud indicators and card fraud acceleration indicators.

[0056] FIG. **5A** depicts a matrix used by an example point-of-compromise detection system. FIGS. **5B-5F** represent how different types of collected data can affect the matrix. The collected data may cause any combination of modifications exemplified in FIGS. **5B-5F** or others. The matrix of FIG. **5A** includes rows of transaction cards and columns of locations. In the matrix, the fraud cards are denoted as  $C_1, C_2, C_3, \dots, C_i$ . For each card  $C_i$ , the system collects all the locations where the  $C_i$  had known or suspicious fraud transactions in a time window and locations in the same time window where the  $C_i$  had non-fraud transactions and transaction times before the latest known or suspicious fraud transaction. The locations can be a physical location like a gas station or restaurant, or a branch of the chain stores in the same ZIP code or area, or a brand, or even a website. The system denotes a collection of all distinct locations from all the above fraud cards as  $L_1, L_2, L_3, \dots, L_j$ . The transaction locations could be hierarchal. For example, a gas station and its branch or brand could be listed and treated equally as transaction locations in the algorithm. In an exemplary embodiment, the system starts with the assumed state that there are no known points-of-compromise or compromised cards have been reissued or replaced. Reissued or replaced cards are not included in the monitoring and analysis system, unless they have new fraud transactions.

[0057] The system constructs a matrix  $M$  with all  $L_j$  as the columns and all  $C_i$  as the rows. The

matrix cell  $m_{ij}$  takes value of 1 if  $C_i$  had transactions in the past 6 months at  $L_j$ , otherwise 0. Due to the size of all  $L_j$  together, the matrix  $M$  would be sparse with many of the cells having value of 0. There is additional row at the matrix bottom, which is the total number of distinct cards that had transactions at each  $L_j$  at the same time window.

[0058] After a time interval such as a day or a week, the system updates the matrix  $M$ . Updates to the matrix are adjustable, including a few hours, a few days, a few weeks, or even a few months. Once the time interval length is set, the system performs consecutive monitoring and analysis on the matrix  $M$  at each interval. The following description provides five sample update scenarios (shown in FIGS. 5B-5F). In practice, the update could be any mixtures of these five scenarios.

[0059] FIG. 5B depicts a modified matrix as compared to the matrix of FIG. 5A after a new time interval has passed, where no known or suspicious transactions occurred. In this case, the last row, which represents the total number of cards used at each location, is the only part of the matrix that is updated by the point-of-compromise detection system.

[0060] In the modified matrix of FIG. 5B, all the zeros and ones remain the same, and even the last row remains the same, meaning no known or suspicious fraud transactions occurred during the current interval and no new card had transactions at any of the locations. Or all the zeros and ones remain the same, but some cells of the last row get updates, meaning no known or suspicious fraud transactions occurred, but there were some new cards that had transactions at some of the locations. In the modified matrix of FIG. 5B, the 2<sup>sup</sup>.nd and 4<sup>sup</sup>.th cells of the last row are updated as some new cards had non-fraud transactions at these locations.

[0061] FIG. 5C shows a modified matrix as compared to the matrix of FIG. 5A after a new time interval has passed, where new fraudulent or suspicious transactions have occurred at locations already contained within the matrix and at specific locations where cards have had previous fraudulent transactions. This means that this specific location/card pair has had previous fraudulent or suspicious transactions. In this case, the point-of-compromise detection system increments, by one, the non-zeros representing previous fraudulent or suspicious transactions at any location for this card.

[0062] In the matrix of FIG. 5C, some cards had new fraud transactions at the locations where they had transactions before. At the row where the card is, the system updates all the one's to two's, while all zeros remain the same. Note a card might have multiple fraud transactions at different locations where the card had transactions before during the same interval and the system updates the one's to two's, not to three or more for the current interval. As such, the system provides weights to frequent fraud cards, and in the meantime, avoid giving over weights. Below is an illustration example where card  $C_5$  had new fraud transaction at location  $L_1$ . Note that the value at the cell  $L_5$  is updated to 2 as well. The last row of the matrix  $M$  remains the same because the existing cards had transactions at the existing locations.

[0063] FIG. 5D illustrates a modified matrix as compared to the matrix of FIG. 5A after a new time interval has passed, where new fraudulent or suspicious transactions have occurred at locations already contained within the matrix and at specific locations where cards have not had previous fraudulent transactions. This means that these locations have had other fraudulent or suspicious transactions with other cards, but has not had fraudulent or suspicious transactions with this particular card. In this case, the point-of-compromise detection system updates the zeroes to ones where the new fraud transactions occurred. The point-of-compromise detection system also increments, by one, the non-zeros representing previous fraudulent or suspicious transactions at other locations.

[0064] In the matrix of FIG. 5D, some cards had new fraud transactions at the locations but they did not have transactions before and the locations already exist in the matrix  $M$ . The system updates the zero's to one's where the fraud transactions occurred, and updates the one's at the same row to two's. All the other zero's at the same row remain the same. Below is an illustration example where value of the cell  $m_{1,1}$  is changed from 0 to 1 as card  $C_1$  had new fraud transaction(s) at



location L\_1. Note that all the ones at the same row are updated to two's.

[0065] FIG. 5E depicts a modified matrix as compared to the matrix of FIG. 5A after a new time interval has passed, where new fraudulent or suspicious transactions have occurred at locations not already contained within the matrix. This means that these locations have not had other fraudulent or suspicious transactions with other cards. In this case, the point-of-compromise detection system begins by adding new columns to the matrix representing these new locations. The point-of-compromise detection system also updates the zeroes to ones where the new fraud transactions occurred.

[0066] In the modified matrix of FIG. 5E, some cards had new fraud transactions at the locations which did not exist in the matrix M before. The system expands the matrix M by adding one more location column. All cards that had transactions at the new location from the beginning time window up to the time right before the new fraud transaction occurred, have value of 1, otherwise 0. Below is an illustration example where card C\_2 had new fraud transaction at location L\_9 in the current interval. Note that the cell m\_6,9 also has value of 1 as card C\_6 had transactions at L\_9 that occurred before the new fraud transaction. At the bottom, the new column L\_9 has its corresponding total number of transactions up to the time right before the new fraud transaction occurred.

[0067] FIG. 5F illustrates a modified matrix as compared to the matrix of FIG. 5A after a new time interval has passed, where new fraudulent or suspicious transactions have occurred using new cards that have not previously been involved with fraudulent or suspicious transactions. This means that these new cards are having fraudulent transactions at locations which have had previous fraudulent transactions with other cards. In this case, the point-of-compromise detection system adds new rows to the matrix representing these new cards and sets fraudulent location/card pairs to one.

[0068] In the modified matrix of FIG. 5F, there are new cards that had fraud transactions at some locations in the matrix M. The system expands the matrix M by adding one more row for each of the new cards. Below is an illustration example where a new card C\_7 had fraud transaction(s) at location L\_3. Note that the cells m\_7,4 and m\_7,8 have value of one as card C\_7 had transactions at these locations up to the time right before the new fraud transaction occurred and that the corresponding cells in the last row are updated as well.

[0069] The five scenarios described with reference to FIG. 5B-5F or a mixture of the scenarios are possible updates for the matrix M in interval 1. The matrix can be horizontally and/or vertically expandable. In the meantime, the matrix can be horizontally and/or vertically shrinkable as well.

[0070] At time interval 2, the system updates matrix M. If the same card had fraud transactions in interval 2, the system incrementally updates the values. So, if the value is 1, now it becomes 2, and if it's 2, now it becomes 3, and so on. At the end of each interval, the system continues doing similar incremental updates. In this way, the system continues cumulatively monitoring the card fraud occurrence and interactions with the locations.

[0071] At each interval, after updating the matrix M, the system computes various values with the matrix. First, the system sums all rows (except the last row in cases where the last row represents the total number of cards used at each location) for each column, then takes the ratio of the sum over the total number of cards at the same location, whose value is stored in the last row of the same matrix M. This ratio is a POC (points-of-compromise) indicator. Second, the system sums all columns for each row (except the last row in cases where the last row represents the total number of cards used at each location) to find a card fraud indicator (CFI) value. The system performs the two calculations starting at the initial time window when all the cells of the matrix M only contain zeros or ones. For convenience, the initial time window is interval 0. Starting at interval 1, besides calculating POC indicator and card fraud indicator, the system does two more calculations, including the ratio of (interval 1 POC indicator - interval 0 POC indicator) / interval 0 POC indicator. This ratio is the POC acceleration indicator (PAI). Alternatively, the PAI can be defined as the ratio of (most recent interval POC indicator - second most recent interval POC indicator) / initial interval

POC indicator. The system also determines the ratio of (interval 1 card fraud indicator-interval 0 card fraud indicator)/interval 0 card fraud indicator (or the ratio in accordance with the alternate definition) to find a card fraud acceleration indicator. These computations continue for interval 2, interval 3, and so on.

[0072] At each interval, the system assesses the three measures: POC indicator, POC acceleration indicator, and card fraud acceleration indicator. The POC indicator works well when the total number of cards at the locations, which is stored in the last row of the matrix M, is relatively small. For instance, if a small coffee shop had 30 cards that had transactions in the past interval, and if, after one or more than one intervals, 10 of them had fraud in various locations, its POC indicator would be  $\frac{1}{3}$ . The population of the cards used in the coffee shop was small, and the POC indicator was relatively high. Thus, this measure makes the coffee shop stand out as a potential POC, which needs follow-up investigations. The matrix M is configured such that whenever a card has a fraud transaction at a location, all other locations where the same card had transactions in the past, get updated. If a card is compromised at a location, it is likely to be used somewhere else. With the matrix M, the system keeps tracks of the past locations of a card which had a new fraud transaction. If the updates of multiple cards connect to a common location, its POC indicator and/or POC acceleration indicator would be high which makes it stand out as a potential POC. In at least one embodiment, the system receives data confirming or not confirming the potential POC as a compromised location.

[0073] Another feature of the matrix M is that the system keeps the cumulative information of all card transactions up to current time interval. Even if the system makes discrete interval observations, each time, the system observes all the information up to current. A compromise window usually is a short time of period like just a few days. In an example embodiment, the system has a cumulative card transaction history, so that the system can avoid breaking up a possible compromise window and not detecting a POC. The system can adjust the observation intervals if needed to promptly catch any short compromise windows. If a card has new fraud transactions, the system incrementally updates the related cells in the matrix M. This way, the system gives proper weights to the frequent fraud cards in the three measures. If a card has frequent fraud transactions over observation intervals, the card fraud acceleration indicator would have high values over consecutive observation intervals, which can help determine if there is a need to reissue or replace this card.

[0074] The POC acceleration indicator works well when the total number of cards at the locations is relatively large. A Walmart location, for example, might have 1000 cards that were used in store recently. If 5 cards had subsequent fraud transactions in the first observation interval, 15 cards in the second observation interval, and 45 cards in the third observation interval, the three POC indicator values would not be high, but the two consecutive POC acceleration indicators would be high. The high POC acceleration indicators show a possible POC at this Walmart location. In at least one embodiment, the system uses the three measures together to make optimal business decisions.

[0075] After the system determines a location had cards that were compromised, the system sends instructions to reissue or replace these compromised cards even if they did not have any fraud transactions, which are usually the majority part of the total cards in the last row of the matrix M. For the fraud cards in the matrix M, if they have been reissued or replaced, they are removed from the matrix M. After fraud cards (rows) from the matrix are removed from the matrix, some columns (locations) might only have value of zeros as the matrix M is sparse and such columns can be removed as well. Therefore, the matrix M could be horizontally and/or vertically shrinkable. On the other hand, if any cards in the matrix whose latest fraud transactions occurred already 6 months ago (beyond the length of the initial time window), and these cards did not belong to any POC events yet, the system removes these old fraud cards, thereby shrinking the dimension of the matrix M. Such sizing of the matrix can be done at every observation interval to make the matrix M ready for

expansion at the next observation interval.

[0076] Referring now to FIGS. 6A-6C, there are three matrices **610**, **620**, and **630** which represent three adjacent time intervals. The matrices **610**, **620**, and **630** show the card fraud indicator, the card fraud acceleration indicator, the POC indicator, and the POC acceleration indicator. The card fraud indicator is generated by summing all values for a specific card (sum all the numbers in a row). For example, in matrix **610**, the card fraud indicator for card 1 (C1) is 3, for C2 is 2, for C3 is 3, for C4 is 4, etc.

[0077] The card fraud acceleration indicator is generated by calculating the ratio of (interval 1 card fraud indicator–interval 0 card fraud indicator)/interval 0 card fraud indicator. For ease of reading, values that change between intervals are shown in boldface, italics, and underlining. The card fraud acceleration indicator in matrix **620** reflects changes to values from matrix **610** to matrix **620**, or from interval 0 to interval 1. By way of example, C1 changes from matrix 1 to matrix 2 by increasing L3 from 0 to 1, increasing L4 from 1 to 2, and increasing L6 from 1 to 2. The card fraud indicator, thus, increases from 3 in matrix **610** to 6 in matrix **620**. The card fraud accelerator indicator for C1 in matrix **620** is (6 (new fraud indicator)–3 (old fraud indicator))/3 (old fraud indicator) or 1.

[0078] Looking at matrix **630**, because the indicators for C1, C2 and C3 do not change from matrix **620** to matrix **630**, the card fraud acceleration indicator becomes zero (0) again.

[0079] The POC indicator is generated by summing all values for a specific location except the ‘total cards used at location’ row (sum all the numbers in a column except the ‘total cards used at location’ row). For example, in matrix **610**, the POC indicator for location 1 (L1) is 2, for L2 is 2, for L3 is 3, for L4 is 3, etc. The POC acceleration indicator is generated by calculating the ratio of (interval 1 POC indicator–interval 0 POC indicator)/interval 0 POC indicator. So, for example, looking at matrix **610** (interval 0) and matrix **620** (interval 1), the POC indicator for location 3 has increased from 3 to 5 because the fraud numbers at location 3 have increased for C1, C3 and C6. The resulting POC acceleration indicator is, thus, (5 (new POC indicator)–3 (old POC indicator))/3 (old POC indicator) or 0.667.

[0080] Matrix **610** is also provided below.

TABLE-US-00001	Card Fraud	Card Fraud	L1	L2	L3	L4	L5	L6	L7	L8	Indicator	Acceleration	C1	0
0	0	1	0	1	1	0	3	0	C2	1	0	1	0	0
0	0	1	1	1	3	0	C5	1	0	0	0	1	0	0
0	0	1	1	1	3	0	C6	0	1	1	0	0	1	1
0	0	1	3	0	POC	0.095	0.044	0.088	0.333	0.077	0.075	0.064	0.057	n/a
0	0	0	0	0	0	0	0	n/a	n/a	Acceleration	Total	Cards	21	45
0	0	0	0	0	0	0	0	n/a	n/a	Acceleration	Total	Cards	21	45

[0081] Matrix **620** is also provided below.

TABLE-US-00002	Card Fraud	Card Fraud	L1	L2	L3	L4	L5	L6	L7	L8	Indicator	Acceleration	C1	0
0	0	<u>1</u>	<u>2</u>	0	<u>2</u>	2	0	7	<u>1.33</u>	C2	1	0	1	0
0	0	0	0	0	1	1	1	3	0	C5	1	0	0	0
0	1	1	0	0	0	1	3	0	POC	0.095	<u>0.089</u>	<u>0.176</u>	<u>0.556</u>	0.115
Indicator	POC	0	<u>1</u>	<u>1</u>	<u>0.670</u>	0.494	<u>0.667</u>	<u>0.334</u>	<u>0.5</u>	n/a	n/a	Acceleration	Total	Cards
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

[0082] Matrix **630** is also provided below.

TABLE-US-00003	Card Fraud	Card Fraud	L1	L2	L3	L4	L5	L6	L7	L8	Indicator	Acceleration	C1	0
0	0	1	2	0	2	2	0	7	<u>0</u>	C2	1	0	1	0
0	0	0	0	<u>2</u>	<u>2</u>	<u>2</u>	<u>6</u>	<u>1</u>	C5	1	0	0	0	0
1	0	0	0	0	1	3	0	POC	0.095	0.089	0.176	0.556	0.115	<u>0.150</u>
Indicator	POC	0	<u>0</u>	<u>0</u>	<u>0</u>	0	<u>0.2</u>	<u>0.208</u>	<u>0.253</u>	n/a	n/a	Acceleration	Total	Cards
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

[0083] Each of the matrices **251-253** of FIG. 2, **351-353** of FIG. 3, the matrices of FIGS. 5A-5F and **610-630** of FIGS. 6A-6C can be implemented as a memory array, such as a static random access memory (SRAM) array, which is described in further detail below.

[0084] During the consecutive monitoring, when the system calculates the card fraud indicator (CFI), the point of compromise indicator (POC), and the POC acceleration indicator (PAI), the system builds (e.g., generates, creates) a CFI trend table and a POC & PAI trend table. FIG. 7A depicts an example CFI trend table 710. The CFI trend table 710 of FIG. 7A is from interval 0 to interval 7. The CFI trend table 710 of FIG. 7A includes rows of transaction cards and columns of intervals. In the example CFI trend table 710, the CFI values at interval 0 were 1, as the system selected credit cards that had at least one fraud transactions in the initial interval, or null, as some cards did not have any fraud transaction yet. At interval 1, cards C1 and C4 had new fraud transactions, so their CFI values increased to 2. The other cards still had CFI value of 1 or null, as they did not have new fraud transactions in this interval. At interval 7, cards C1 and C3 had high CFI values compared to the other cards. This could help the card issuer make a prompt decision to reissue or replace these two cards.

[0085] The CFI trend table 710 is also provided below.

TABLE-US-00004	CFI0	CFI1	CFI2	CFI3	CFI4	CFI5	CFI6	CFI7	C1	1	2	3	4	5	6	7	C2	1	1	2	2	2	2	3	3	C3	1	1	1	2	2	3	4	5	C4	1	2	2	2	2	2	3	C5	1	1	1	1	1	1	1	1	C6	null	null	1	1	2	2	2	2
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[0086] FIG. 7B depicts an example POC & PAI trend table 720. The POC & PAI trend table 720 of FIG. 7B is from interval 0 to interval 3. The POC & PAI trend table 720 of FIG. 7B includes rows of transaction cards and columns of metrics (POC and PAI) at various intervals. As the intervals progress, the POC/PAI values of merchant L1 continued increasing much faster than the other merchants. It was likely that the merchant was a potential point of compromise, and the card issuer should take further investigation on this merchant.

[0087] The POC & PAI trend table 720 is also provided below.

TABLE-US-00005	Total Cards	POC0	PAI0	POC1	PAI1	POC2	PAI2	POC3	PAI3	L1	4459	0.00292	0	0.00336	0.1507	0.00538	0.6919	0.00695	0.5377	L2	24838	0.00004	0	0.00004	0	0.00004	0	0.00008	1	L3	1565	0.00317	0	0.00317	0	0.00317	0	0.00317	0	L4	3601	0.00028	0	0.00028	0	0.00056	1	0.00083	1.9643	L5	17532	0.00006	0	0.00006	0	0.00006	0	0.00006	0	L6	39855	0.00003	0	0.00003	0	0.00008	1.6667	0.0001	0.6667
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[0088] In some embodiments, a cut-off (e.g., threshold) is selected for the POC and the PAI, and any locations with a POC or PAI are identified as (potential) points of compromise. However, when there are many merchants included in the POC & PAI trend table, it is sometimes difficult to select a cut-off point on POC and PAI values to separate out potential points of compromise out. To address this issue, the system can filter out third-party merchants that the card issuer may be less liable for. These types of merchants may include big virtue/on-line brands or websites with a high volume of card transactions where fraud transactions were frequently observed. By removing these types of merchants, the total number of cards used at each location in the trend table may be more comparable with each other. In addition, filtering improves computation efficiency as it is time consuming to calculate the total number of cards used at each location for the merchants with a high volume of transactions.

[0089] Another strategy is to segment the merchants into different groups and compare the POC & PAI values inside each group. There may not be a hard cut-off point of the POC & PAI values across different groups. Each group may have its own cut-off point that may be determined based on business knowledge. In one example of segmentation, a compromised card is then used for fraud in nearby gas stations or restaurants. The system can segment the merchants according to geolocations. The system can also segment the merchants according to business types as different businesses might have different fraud patterns or frequencies. The system can put all gas stations into one group, all fast food chain stores into another group, and so on. Another option is that the system segments the merchants based on the range of the total number of cards used at each location, such as [0,5000], [5001,20000], [20001,100000], and [100001 and beyond]. The total number of cards used at each location are an indicator of the transaction traffic, which is highly correlated with the number of fraud transactions. The outliers of the POC/PAI values inside each

group could be a point-of-compromise suspect that needs further investigations from the card issuer.

[0090] The system can determine a starting and ending date of the compromise event. All cards that had transactions at the location and in the time window can be compromised. The cards that had transactions at the location but not in the time window are treated as having normal transactions. In an example, the initial interval started on 2018 Nov. 1, ended on 2019 Apr. 7. We cut the interval into a-week-long slices. Below show the ending dates of the granular slices:

[0091] '2018 Nov. 4', '2018 Nov. 11', '2018 Nov. 18', '2018 Nov. 25', '2018 Dec. 2', '2018 Dec. 9', '2018 Dec. 16', '2018 Dec. 23', '2018 Dec. 30', '2019 Jan. 6', '2019 Jan. 13', '2019 Jan. 20', '2019 Jan. 27', '2019 Feb. 3', '2019 Feb. 10', '2019 Feb. 17', '2019 Feb. 24', '2019 Mar. 3', '2019 Mar. 10', '2019 Mar. 17', '2019 Mar. 24', '2019 Mar. 31', '2019 Apr. 7'

[0092] The system calculates the number of distinct credit cards that had transactions at the compromised location in each slice prior to the respective card's latest fraud transaction in this interval. At the second monitoring interval ending on 2019 Apr. 14, the system extends the granular slice list by adding the slice of 2019 Apr. 14 to the end:

[0093] '2018 Nov. 4', '2018 Nov. 11', '2018 Nov. 18', '2018 Nov. 25', '2018 Dec. 2', '2018 Dec. 9', '2018 Dec. 16', '2018 Dec. 23', '2018 Dec. 30', '2019 Jan. 6', '2019 Jan. 13', '2019 Jan. 20', '2019 Jan. 27', '2019 Feb. 3', '2019 Feb. 10', '2019 Feb. 17', '2019 Feb. 24', '2019 Mar. 3', '2019 Mar. 10', '2019 Mar. 17', '2019 Mar. 24', '2019 Mar. 31', '2019 Apr. 7', '2019 Apr. 14'

[0094] The system calculates the number of distinct credit cards that had transactions at the compromised location in each slice prior to their latest fraud transaction up to the date of 2019 Apr. 14. The same calculation is repeated at each new interval, and a plot of the granular slice list versus the number of distinct cards is generated, which can be referred to as the mass count plot. FIG. 8A depicts an example mass count plot **810**. The mass count plot **810** shows the granular slices from 2018 Nov. 4 to 2019 Jun. 30. After a few more intervals, the mass count plot **810** shows a clear spike, and the associated date is usually close to when the compromise event gets started. When a compromise event takes place, the information of many cards is abruptly exposed to the hacker, and then used afterwards for fraud transactions. This leads to a spike in the mass count plot **810**. Conversely, the system can uncover the compromise starting date with the spike. The mass count plot **810** can be arranged as a list (e.g., the mass count list). In the example, the mass count list has 35 entries.

[0095] FIG. 8B depicts an example sub-list **820**. The system determines a median of the mass count list. Then the system generates the sub-list **820** by selecting points from the mass count list that have greater value than the median.

[0096] The sub-list **820** has 13 entries, where the second entry, the slice of 2019 Feb. 17, has the highest count. The first entry is the slice of 2019 Feb. 10 and there is no time gap between the two slices. As the first entry has high counts and does not have a time gap with the spike, the system can claim the starting date of the compromise event was in the slice of 2019 Feb. 10. The earliest starting date could be 2019 Feb. 4, as it was the beginning of the slice. It's challenging to determine the ending date of the compromise event, as the event might be still ongoing when the system tries to detect the compromise window. The first eight entries of the above sub-list **820** are all adjacent to each other in terms of time. From the ninth entry, there are time gaps with neighboring slices. The system's last observation is on 2019 Jun. 30. Normally, when close to the observation date, the mass counts will be getting less and less as the time is getting tight for the compromised cards to be used for fraud. However, there are still see frequent entries that were greater than the median count of the mass count list. The last entry with the mass count greater than the median is the slice of 2019 Jun. 9, only 3 weeks away from 2019 Jun. 30. Normally, the mass count of the recent entries would not be high, and a legitimate reason would be that the compromise event was still active when we were making the last observation on 2019 Jun. 30. This condition can be seen from the above mass count plot **810**, where most of the counts at the lower right corner are much higher than

those at the lower left corner.

[0097] It could be very useful for the card issuer that the system can use the mass count list and the mass count plot **810** to help determine an ongoing compromise event. The system and/or the card issuer can take prompt actions to stop the ongoing compromise event and save business losses.

FIG. **8C** depicts an example sub-list **830**. The sub-list **830** is that of the mass count list of another compromise event, which originally contains 60 one-week-long slices from 2018 Jul. 8 to 2019 Aug. 25. The entries of the sub-list below are all greater than the median of the mass count list. The entry of 2019 May 5 has the highest count. The entry before the highest mass count is the slice of 2019 Mar. 31. There is an apparent time gap between the two entries, which is different from the first mass count list example. In this case, the system treats the preceding slices as white noises, and claims the starting date of the compromise event is in the slice of 2019 May 5, which could be as early as 2019 Apr. 29. In the two examples, the system consistently determines the compromise event starting date in or near the time slice with the highest mass count. The starting date could be in one of the entries before the one with the highest mass count, but there must be no time gap among the entry with the starting date, the entry with the highest mass count, and any entries in between.

[0098] From the entry of 2019 May 5 to the one of 2019 Jun. 30, all the nine entries are adjacent to each other in terms of time. There is no more entry after 2019 Jun. 30 with the mass count greater than the median of the original mass count list, even though the list ended at the slice of 2019 Aug. 25. Therefore, we claim the ending date of the compromise event is in the slice of 2019 Jun. 30. This compromise event has a clear ending date. It might start on 2019 Apr. 29 and end on 2019 Jun. 30. All cards that had transactions at the merchant during this time period could be the victims of the compromise event. FIG. **8D** depicts an example mass count plot **840**. The mass count plot **840** of the compromise event shows the time slices from 2018 Jul. 8 to 2019 Aug. 25.

[0099] In the mass count plot **840**, most of the mass counts of recent time slices at lower right corner are lower than those at lower left corner. At the upper right area of the plot, the time slices from 2019 May 5 to 2019 Jun. 30 with the highest mass counts clustered together, which indicate the time window of the compromise event.

[0100] From the two examples, the decision rules of using the mass count list and mass count plot (e.g., mass count plot **810**, mass count plot **840**) can be summarized as follows:

[0101] The starting date of the compromise window is either in the time slice with the highest mass count, or in one of the preceding slices once there is no time gap among the slices and all the slices in between having mass count greater than the median of the list.

[0102] The ending date of the compromise window could be the last observation date, especially when there are frequent late recent slices with high mass counts greater than the median of the list. Alternatively, the ending date could be before the last observation date. It would be after the starting date and within one the following slices, without any time gap, whose mass counts are all greater than the median of the list.

[0103] When a credit card is determined to be compromised, the card issuer may reissue a new card to the card holder. The card holder may not reactivate the new card, meaning the card holder abandons the new card. Even if the card holder reactivates it, the card holder may significantly reduce the transaction frequencies and amounts using the new card. Therefore, the card issuer might lose a valuable customer or have reduced revenue. In weighing the risks, certain cases may call for reissue while other cases may not. By way of example, when a compromise event has 100 compromised cards detected by the methods proposed in the above sections, and 20 of them already committed to fraud, it might be a good idea for the card issuer to take a prompt action to replace the remaining 80 cards even if they haven't had any fraud transactions yet. However, when an event has 1000 compromised cards, and only 50 of them have committed to fraud, the card issuer might have to consider the balance between the reactivation rate and the severity level of the compromise event. To identify the best cases for reissue, the system can reissue score to each of the

compromised cards based on the severity level of the compromise event and the transaction characteristics of the cards so that the card issuer can only reissue new cards to those with high scores.

[0104] In some embodiments, the system uses the POC and PAI values to quantify the severity level of the compromise event. As the POC and PAI values increase when entering a new monitoring interval, the associated reissue scores will be getting higher as well, which means more cards need to be considered for replacement. In some embodiments, the system uses the CFI for reissue strategy as well. To determine the other modeling features, the system can select one month most recent transaction records of each compromised card that occurred at least one week prior to the initial interval ending date. For example, the system chooses the following features: the number of merchants where the card had transactions; the number of states where the card had transactions; the last transaction amount; the average risk score; the last visa risk code; the average visa risk code; the customer bin; the number of days since the card opened; the number of days since the card issued last time; and the number of swiped card transactions.

[0105] Among the features, only the customer-bins feature is categorical, while the others are numeric. As the reissue score model is built for each individual compromise event, all the cards in the event share the same POC & PAI values at the same interval. To obtain variations of the POC & PAI values, the system repeats the initial feature set 5-6 times, each time assigned with the POC & PAI values and the fraud labels of a different time interval. Then the system stacks all the sets together as a single training set.

[0106] FIG. 9A is an area under the curve (AUC) plot **910** of a training set with AUC value of 0.89. FIG. 9B is an AUC plot **920** of a testing set with AUC value of 0.83. The two plots show the reissue score model can predict the probability of a card used in fraud transactions in the coming time intervals. Thus, the card issuer can reissue new cards to those card holders to stop potential losses, and the cards with low reissue scores won't get a unnecessary new card.

[0107] FIG. 10 is a diagram of a memory device **1000**, in accordance with one embodiment. In some embodiments, the memory device **1000** includes a memory controller **1005** and a memory array **1020**. The memory array **1020** may include a plurality of storage circuits or memory cells **1025** arranged in two- or three-dimensional arrays. Each memory cell **1025** may be coupled to a corresponding word line WL and a corresponding bit line BL. The memory controller **1005** may write data to or read data from the memory array **1020** according to electrical signals through word lines WL and bit lines BL. In other embodiments, the memory device **1000** includes more, fewer, or different components than shown in FIG. 10.

[0108] The memory array **1020** is a hardware component that stores data. In some embodiments, the memory array **1020** is embodied as a semiconductor memory device. The memory array **1020** includes a plurality of storage circuits or memory cells **1025**. The memory array **1020** includes word lines WL0, WL1 . . . . WLJ, each extending in a first direction (e.g., X-direction) and bit lines BL0, BL1 . . . . BLK, each extending in a second direction (e.g., Y-direction). The word lines WL and the bit lines BL may be conductive metals or conductive rails. In some embodiments, each memory cell **1025** is coupled to a corresponding word line WL and a corresponding bit line, and can be operated according to voltages or currents through the corresponding word line WL and the corresponding bit line BL. In some embodiments, the memory array **1020** includes additional lines (e.g., select lines, reference lines, reference control lines, power rails, etc.).

[0109] In some embodiments, each word line WL corresponds to a transaction card (e.g., transaction cards **301**, **302**, **303**, and **304**) and each BL corresponds to a points-of-sale device (e.g., point-of-sale devices **311**, **312**, and **313**). A memory cell that stores a one (e.g., a high voltage level, VDD, supply voltage, etc.) indicates an event (e.g., a fraud transaction, a non-fraud transaction occurring before a latest fraud transaction, etc.) for the transaction card corresponding to the memory cell's WL at the point-of-sale device/location corresponding to the memory cell's BL. A memory cell that stores a zero (e.g., a low voltage level, zero volts, ground voltage, etc.) indicates

that no such event occurred. In some embodiments, the memory cell can store more than two states (e.g., the memory cell can store 4 states, wherein a one indicates only one event has occurred, a two indicates two events have occurred, and a three indicates that three or more events have occurred). In some embodiments, an indication of multiple events can be stored by assigning multiple BLs to one point-of-sale device (and/or assigning multiple WLs to one transaction card). For example, first point-of-sale device is assigned three BLs (BL1, BL2, and BL3), that are a binary representation of the number of events for a given transaction card at the first point-of-sale device. If a first card transaction has one event at the first point-of-sale device, a one is stored for BL1, a zero is stored for BL2, and a zero is stored for BL3, if the first card transaction has three events at the first point-of-sale device, a one is stored for BL1, a one is stored for BL2, and a zero is stored for BL3, if the first card transaction has two events at the first point-of-sale device, a zero is stored for BL1, a one is stored for BL2, and a zero is stored for BL3, etc.

[0110] In some embodiments, the information regarding suspicious fraud activity is stored in one of multiple tiers of storage. Information that is more likely to be processed in real-time can be stored in a faster storage technology (1st tier), such as SRAM, RAM, or a faster version of flash such solid-state drive (SSD), and information that is less likely to be processed in real-time (archived information) is stored in a slower storage technology (2nd tier), such as DRAM, read-only memory (ROM), or a slower version of flash such as hard disk drive (HDD). For example, the most recent (e.g., the last 3 months of) information regarding suspicious fraud activity is stored in a faster storage technology, and the remainder is stored in a slower storage technology. In another example, the post-processed information (e.g., the POC, PAI, and CFI) is stored in the faster storage technology, and the raw information (e.g., the number of events for a given card and location) is stored in the slower storage technology.

[0111] The memory controller **1050** is a hardware component that controls operations of the memory array **1020**. In some embodiments, the memory array **1020** includes a bit line controller **1012**, a word line controller **1014**, and a timing controller **1010**. In one configuration, the word line controller **1014** is a circuit that provides a voltage or a current through one or more word lines WL of the memory array **1020**, and the bit line controller **1012** is a circuit that provides or senses a voltage or current through one or more bit lines BL of the memory array **1020**. In one configuration, the timing controller **1010** is a circuit that provides control signals or clock signals to synchronize operations of the bit line controller **1012** and the word line controller **1014**. The bit line controller **1012** may be coupled to bit lines BL of the memory array **1020**, and the word line controller **1014** may be coupled to word lines WL of the memory array **1020**. In one example, to write data to a memory cell **1025**, the word line controller **1014** provides a voltage or current to the memory cell **1025** through a word line WL coupled to the memory cell **1025**, and applies a bias voltage to the memory cell **1025** through a bit line BL coupled to the memory cell **1025**. In one example, to read data from a memory cell **1025**, the word line controller **1014** provides a voltage or current to the memory cell **1025** through a word line WL coupled to the memory cell **1025**, and senses a voltage or current corresponding to data stored by the memory cell **1025** through a bit line coupled to the memory cell **1025**. In some embodiments, the memory controller **1005** includes more, fewer, or different components than shown in FIG. **10**.

[0112] FIG. **11** is an example circuit diagram of the memory cell **1025**. As shown in FIG. **6A**, the memory cell **1025** includes cross-coupled inverters **1102A-1102B**, a bit line (BL) at the output of the inverter **1102A**, a transmission gate **1104A** coupling the BL to a word line WL, a bit line bar (BLB) at the output of the inverter **1102B**, a transmission gate **1104B** coupling the BLB to a word line bar WLB. In some embodiments, a first voltage of the weight bit is stored on the BL. In some embodiments, a second voltage of the weight bit is stored on the BLB. In some embodiments, the second voltage is generated at the output of the inverter **1102B** in response to the first voltage being at the input of the inverter **1102B**. In some embodiments, the memory cell **1025** includes a six-transistor (6T) static random access memory (SRAM) cell (e.g., cell core), a two-transistor-two-



resistor (2T-2R) SRAM cell, a four-transistor (4T)-SRAM cell, an eight-transistor (8T)-SRAM cell, a ten-transistor (10T)-SRAM cell, a dynamic random access memory (DRAM) cell, and other types of memory cells that are suitable for use within a memory array, some of which are enumerated in FIG. 12.

[0113] Referring now to FIG. 12, an example block diagram of a computing system **1200** is shown, in accordance with some embodiments of the disclosure. The computing system **1200** may be used by a circuit or layout designer for integrated circuit design. A “circuit” as used herein is an interconnection of electrical components such as resistors, transistors, switches, batteries, inductors, or other types of semiconductor devices configured for implementing a desired functionality. The computing system **1200** includes a host device **1205** associated with a memory device **1210**. The host device **1205** may be configured to receive input from one or more input devices **1215** and provide output to one or more output devices **1220**. The host device **1205** may be configured to communicate with the memory device **1210**, the input devices **1215**, and the output devices **1220** via appropriate interfaces **1225A**, **1225B**, and **1225C**, respectively. The computing system **1200** may be implemented in a variety of computing devices such as computers (e.g., desktop, laptop, servers, data centers, etc.), tablets, personal digital assistants, mobile devices, other handheld or portable devices, or any other computing unit suitable for performing schematic design and/or layout design using the host device **1205**.

[0114] The input devices **1215** may include any of a variety of input technologies such as a keyboard, stylus, touch screen, mouse, track ball, keypad, microphone, voice recognition, motion recognition, remote controllers, input ports, one or more buttons, dials, joysticks, and any other input peripheral that is associated with the host device **1205** and that allows an external source, such as a user (e.g., a circuit or layout designer), to enter information (e.g., data) into the host device and send instructions to the host device. Similarly, the output devices **1220** may include a variety of output technologies such as external memories, printers, speakers, displays, microphones, light emitting diodes, headphones, video devices, and any other output peripherals that are configured to receive information (e.g., data) from the host device **1205**. The “data” that is either input into the host device **1205** and/or output from the host device may include any of a variety of textual data, circuit data, signal data, semiconductor device data, graphical data, combinations thereof, or other types of analog and/or digital data that is suitable for processing using the computing system **1200**.

[0115] The host device **1205** includes or is associated with one or more processing units/processors, such as Central Processing Unit (“CPU”) cores **1230A-1230N**. The CPU cores **1230A-1230N** may be implemented as an Application Specific Integrated Circuit (“ASIC”), Field Programmable Gate Array (“FPGA”), or any other type of processing unit. Each of the CPU cores **1230A-1230N** may be configured to execute instructions for running one or more applications of the host device **1205**. In some embodiments, the instructions and data to run the one or more applications may be stored within the memory device **1210**. The host device **1205** may also be configured to store the results of running the one or more applications within the memory device **1210**. Thus, the host device **1205** may be configured to request the memory device **1210** to perform a variety of operations. For example, the host device **1205** may request the memory device **1210** to read data, write data, update or delete data, and/or perform management or other operations. One such application that the host device **1205** may be configured to run may be a standard cell application **1235**. The standard cell application **1235** may be part of a computer aided design or electronic design automation software suite that may be used by a user of the host device **1205** to use, create, or modify a standard cell of a circuit. In some embodiments, the instructions to execute or run the standard cell application **1235** may be stored within the memory device **1210**. The standard cell application **1235** may be executed by one or more of the CPU cores **1230A-1230N** using the instructions associated with the standard cell application from the memory device **1210**. In one example, the standard cell application **1235** allows a user to utilize pre-generated schematic

and/or layout designs of the memory device **100** or a portion of the memory device **100** to aid integrated circuit design. After the layout design of the integrated circuit is complete, multiples of the integrated circuit, for example, including the memory device **100** or a portion of the memory device **100** can be fabricated according to the layout design by a fabrication facility.

[0116] Referring still to FIG. **12**, the memory device **1210** includes a memory controller **1240** that is configured to read data from or write data to a memory array **1245**. The memory array **1245** may include a variety of volatile and/or non-volatile memories. For example, in some embodiments, the memory array **1245** may include NAND flash memory cores. In other embodiments, the memory array **1245** may include NOR flash memory cores, SRAM cores, Dynamic Random Access Memory (DRAM) cores, Magnetoresistive Random Access Memory (MRAM) cores, Phase Change Memory (PCM) cores, Resistive Random Access Memory (ReRAM) cores, 3D XPoint memory cores, ferroelectric random-access memory (FeRAM) cores, and other types of memory cores that are suitable for use within the memory array. The memories within the memory array **1245** may be individually and independently controlled by the memory controller **1240**. In other words, the memory controller **1240** may be configured to communicate with each memory within the memory array **1245** individually and independently. By communicating with the memory array **1245**, the memory controller **1240** may be configured to read data from or write data to the memory array in response to instructions received from the host device **1205**. Although shown as being part of the memory device **1210**, in some embodiments, the memory controller **1240** may be part of the host device **1205** or part of another component of the computing system **1200** and associated with the memory device. The memory controller **1240** may be implemented as a logic circuit in either software, hardware, firmware, or combination thereof to perform the functions described herein. For example, in some embodiments, the memory controller **1240** may be configured to retrieve the instructions associated with the standard cell application **1235** stored in the memory array **1245** of the memory device **1210** upon receiving a request from the host device **1205**.

[0117] It is to be understood that only some components of the computing system **1200** are shown and described in FIG. **12**. However, the computing system **1200** may include other components such as various batteries and power sources, networking interfaces, routers, switches, external memory systems, controllers, etc. Generally speaking, the computing system **1200** may include any of a variety of hardware, software, and/or firmware components that are needed or considered desirable in performing the functions described herein. Similarly, the host device **1205**, the input devices **1215**, the output devices **1220**, and the memory device **1210** including the memory controller **1240** and the memory array **1245** may include other hardware, software, and/or firmware components that are considered necessary or desirable in performing the functions described herein.

[0118] The herein described subject matter sometimes illustrates different components contained within, or connected with, different other components. It is to be understood that such depicted architectures are merely exemplary, and that in fact many other architectures can be implemented which achieve the same functionality. In a conceptual sense, any arrangement of components to achieve the same functionality is effectively “associated” such that the desired functionality is achieved. Hence, any two components herein combined to achieve a particular functionality can be seen as “associated with” each other such that the desired functionality is achieved, irrespective of architectures or intermedial components. Likewise, any two components so associated can also be viewed as being “operably connected,” or “operably coupled,” to each other to achieve the desired functionality, and any two components capable of being so associated can also be viewed as being “operably couplable,” to each other to achieve the desired functionality. Specific examples of operably couplable include but are not limited to physically mateable and/or physically interacting components and/or wirelessly interactable and/or wirelessly interacting components and/or logically interacting and/or logically interactable components.

[0119] With respect to the use of substantially any plural and/or singular terms herein, those having

skill in the art can translate from the plural to the singular and/or from the singular to the plural as is appropriate to the context and/or application. The various singular/plural permutations may be expressly set forth herein for sake of clarity.

[0120] It will be understood by those within the art that, in general, terms used herein, and especially in the appended claims (e.g., bodies of the appended claims) are generally intended as “open” terms (e.g., the term “including” should be interpreted as “including but not limited to,” the term “having” should be interpreted as “having at least,” the term “includes” should be interpreted as “includes but is not limited to,” etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, as an aid to understanding, the following appended claims may contain usage of the introductory phrases “at least one” and “one or more” to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles “a” or “an” limits any particular claim containing such introduced claim recitation to inventions containing only one such recitation, even when the same claim includes the introductory phrases “one or more” or “at least one” and indefinite articles such as “a” or “an” (e.g., “a” and/or “an” should typically be interpreted to mean “at least one” or “one or more”); the same holds true for the use of definite articles used to introduce claim recitations. In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should typically be interpreted to mean at least the recited number (e.g., the bare recitation of “two recitations,” without other modifiers, typically means at least two recitations, or two or more recitations). Furthermore, in those instances where a convention analogous to “at least one of A, B, and C, etc.” is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., “a system having at least one of A, B, and C” would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). In those instances where a convention analogous to “at least one of A, B, or C, etc.” is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., “a system having at least one of A, B, or C” would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). It will be further understood by those within the art that virtually any disjunctive word and/or phrase presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of including one of the terms, either of the terms, or both terms. For example, the phrase “A or B” will be understood to include the possibilities of “A” or “B” or “A and B.” Further, unless otherwise noted, the use of the words “approximate,” “about,” “around,” “substantially,” etc., mean plus or minus ten percent.

[0121] The foregoing description of illustrative embodiments has been presented for purposes of illustration and of description. It is not intended to be exhaustive or limiting with respect to the precise form disclosed, and modifications and variations are possible in light of the above teachings or may be acquired from practice of the disclosed embodiments. It is intended that the scope of the invention be defined by the claims appended hereto and their equivalents.

## Claims

**1.-20.** (canceled)

**21.** A method for identifying point-of-compromise locations in a transaction card network, the method comprising: monitoring, by a computing system, transaction data for a plurality of transaction cards across a plurality of time intervals; constructing, by the computing system, a multidimensional data structure wherein: a first dimension corresponds to the plurality of

transaction cards, a second dimension corresponds to a plurality of merchant locations, and a third dimension corresponds to the plurality of time intervals; for each transaction card of the plurality of transaction cards that performed a non-fraudulent transaction at a first merchant location and subsequently performed a fraudulent transaction at any location, incrementing, by the computing system, a corresponding counter in the multidimensional data structure; calculating, by the computing system, a point-of-compromise (POC) indicator for each merchant location by determining a ratio of a sum of counter values for the merchant location to a total number of transaction cards used at the merchant location; calculating, by the computing system, a POC acceleration indicator for each merchant location by determining a rate of change of the POC indicator over at least two consecutive time intervals; identifying, by the computing system, a candidate POC location based on at least one of the POC indicator or the POC acceleration indicator exceeding a predetermined threshold; generating, by the computing system, a mass count plot showing a number of transaction cards having suspicious fraud activity at the candidate POC location for each of a plurality of time slices; and determining, by the computing system, a window of compromise at the candidate POC location based on identifying a time slice with a highest count in the mass count plot and at least one adjacent time slice having a count higher than a median count.

**22.** The method of claim 21, further comprising: calculating, by the computing system, a card fraud indicator (CFI) for each transaction card by summing all counter values across merchant locations for the transaction card; calculating, by the computing system, a card fraud acceleration indicator by determining a rate of change of the CFI over at least two consecutive time intervals; and prioritizing transaction cards for reissuance based on the card fraud acceleration indicator.

**23.** The method of claim 21, wherein determining the window of compromise further comprises: determining a starting date of the window of compromise as a beginning of a time slice that has no time gap with the time slice having the highest count; and determining an ending date of the window of compromise as an end of a last consecutive time slice having a count greater than the median count.

**24.** The method of claim 21, further comprising: segmenting, by the computing system, the plurality of merchant locations into groups based on at least one of: a geographical location, a merchant type, a transaction volume range, or a brand affiliation; and applying different POC indicator thresholds to each group.

**25.** The method of claim 21, further comprising: identifying transaction cards that were used at the candidate POC location within the window of compromise; calculating a reissue score for each identified transaction card based on: the POC indicator, the POC acceleration indicator, and transaction characteristics of the transaction card; and selectively issuing instructions to reissue only transaction cards having a reissue score above a predetermined threshold.

**26.** The method of claim 25, wherein the transaction characteristics include at least three of: a number of merchants where the transaction card had transactions, a number of states where the transaction card had transactions, a last transaction amount, an average risk score, a visa risk code, a customer bin, a number of days since the transaction card was opened, a number of days since the transaction card was last issued, or a number of swiped transactions.

**27.** The method of claim 21, further comprising: determining transaction cards that had non-fraudulent transactions at the candidate POC location outside the window of compromise; and removing data associated with those transaction cards from the multidimensional data structure.

**28.** A system for detecting points-of-compromise in a transaction card network, the system comprising: a network interface configured to receive transaction data from a plurality of point-of-sale terminals; memory comprising a hierarchical storage system including: a first tier of faster storage technology for storing recent transaction data and post-processed indicators, and a second tier of slower storage technology for storing historical transaction data; one or more processors coupled to the memory and programmed to: maintain a three-dimensional matrix in the first tier of

faster storage technology, the three-dimensional matrix comprising: a first dimension representing transaction cards, a second dimension representing merchant locations, and a third dimension representing time intervals; determine suspicious fraud activity based on patterns in the three-dimensional matrix; identify a candidate point-of-compromise (POC) location; generate a mass count plot showing numbers of transaction cards having suspicious fraud activity at the candidate POC location across a plurality of time slices; identify a compromise time window based on the mass count plot; calculate a reissue score for each transaction card used at the candidate POC location during the compromise time window; and trigger a selective card reissue process based on the calculated reissue scores.

**29.** The system of claim 28, wherein the faster storage technology comprises static random access memory (SRAM) arrays, and wherein the slower storage technology comprises at least one of dynamic random access memory (DRAM) or flash storage.

**30.** The system of claim 28, wherein the one or more processors are further programmed to: detect an ongoing compromise event by identifying a persistent elevated level of suspicious activity in recent time slices of the mass count plot; and trigger an emergency response protocol if an ongoing compromise event is detected.

**31.** The system of claim 28, wherein the one or more processors are further programmed to: train a machine learning model using historical transaction data and associated fraud indicators to predict a likelihood of a transaction card being used in future fraudulent transactions; and incorporate predictions from the machine learning model into the reissue score calculation.

**32.** The system of claim 28, wherein the one or more processors are further programmed to: generate a POC trend table and a card fraud indicator (CFI) trend table for monitoring POC indicators, POC acceleration indicators, and card fraud indicators across multiple time intervals; and provide visual representations of the trend tables through a user interface.

**33.** The system of claim 28, wherein the one or more processors are further programmed to: filter out third-party merchants with high transaction volumes from POC analysis based on predetermined criteria; and segment remaining merchants into different groups based on business types, geographic regions, or transaction volume ranges.

**34.** The system of claim 28, wherein the one or more processors are further programmed to: generate a consolidated report for a card issuer identifying: the candidate POC location, the compromise time window, a severity level of the compromise event, a count of affected cards, estimated potential fraud losses, and recommended remediation actions.

**35.** An apparatus for identifying compromised transaction cards, the apparatus comprising: a memory device; and a processor having programmed instructions stored in the memory device that when executed cause the processor to: receive suspicious fraud activity data for a plurality of transaction cards; store the suspicious fraud activity data in a memory array implemented as a static random access memory (SRAM) array, wherein: rows of the memory array correspond to transaction cards, columns of the memory array correspond to merchant locations, and each cell of the memory array stores a counter value indicating a level of suspicious activity; identify a point-of-compromise (POC) location based on a distribution pattern of the counter values; analyze the suspicious fraud activity data to determine a starting time and an ending time of a compromise event at the POC location; classify each transaction card that conducted a transaction at the POC location into risk categories based on: whether the card's transaction occurred within the compromise event time period, transaction characteristics of the card, and post-compromise transaction patterns of the card; and transmit card-specific remediation instructions based on the risk categories.

**36.** The apparatus of claim 35, wherein the processor is further programmed to: identify hierarchical relationships between merchant locations, wherein a parent merchant location corresponds to a brand and child merchant locations correspond to individual branches; and analyze suspicious fraud patterns at both the parent and child levels to detect compromises

affecting entire brands versus individual locations.

**37.** The apparatus of claim 35, wherein the processor is further programmed to: calculate a combined suspicious activity score based on weighted combinations of: a POC indicator, a POC acceleration indicator, and a card fraud indicator; and dynamically adjust detection thresholds based on historical false positive and false negative rates.

**38.** The apparatus of claim 35, wherein the processor is further programmed to: update the memory array at predefined time intervals by: identifying newly compromised cards, adding new rows to the memory array for the newly compromised cards, adding new columns to the memory array for new merchant locations with suspicious activity, incrementing counters for cards with new fraudulent activity, and removing rows for cards that have been reissued or that have not shown suspicious activity for a predetermined time period.

**39.** The apparatus of claim 35, wherein the processor is further programmed to: calculate and store a reissue priority score for each compromised card based on: a severity level of the compromise event, a card usage pattern, a card holder's spending profile, and a card holder's relationship value to an issuer; and generate tiered reissuance recommendations.

**40.** The apparatus of claim 35, wherein the processor is further programmed to: perform a verification check on identified POC locations by: analyzing geographic clustering of fraudulent transactions following suspected compromise events, comparing time patterns of fraudulent transactions with known compromise event time patterns, and correlating fraudulent transaction characteristics with merchant-specific transaction characteristics; and assign a confidence level to each identified POC location.

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