SYSTEM AND METHOD FOR EXTRACTING AND FORECASTING COMPUTING RESOURCE DATA SUCH AS CPU CONSUMPTION USING AUTOREGRESSIVE METHODOLOGY

The present invention relates to a computer platform, and in particular, to a system and method to forecast the performance of computing resources.

The computing resources of a large business represent a significant financial investment. When the business grows, resource managers must ensure that new resources are added as processing requirements increase. The fact that the growth and evolution of a computing platform is often rapid and irregular complicates management efforts. This is especially true for computing platforms common to banking institutions and telecommunications companies, for example, whose computing platforms typically include hundreds of geographically distributed computers.

To effectively manage the vast resources of a computing platform and to justify any requests for acquisition of new resources, managers need accurate forecasts of computing platform resource performance. However, conventional forecasting tools may not be adequate for use on computing platforms. For example, conventional sales performance forecasting tools, which use linear regression and multivariable regression to analyze data, commonly factor in such causal variables as the effect of holiday demand, advertising campaigns, price changes, etc. Similarly, pollution forecasting tools typically consider the causal effect of variations in traffic patterns. As such, using these tools to forecast computing platform resources may be problematical because causal parameters generally are difficult to establish and are unreliable.

Other conventional forecasting tools may be limited by the amount of data they can process. For example, some forecasting tools may not adequately purge older or non-essential data. Other forecasting tools may not appropriately incorporate new data as it becomes available. Still other forecasting tools may not have the computing power to perform calculations on large amounts of data.

The limitations of established forecasting tools are particularly troublesome when forecasting resources in computing platforms that are expanding or are already re-engineered. These computing platforms need a forecasting system and method that deal appropriately with new data as well as unneeded data. Moreover, these computing platforms need a forecasting system and method that augment causal-based forecasting tools to provide accurate and reliable forecasts.

Presented herein is a system and method to forecast computing platform resource performance that overcomes the limitations associated with conventional forecasting tools. An embodiment applies an autoregressive model to electronically generated empirical data to produce accurate and reliable computing platform resource performance forecasts. An embodiment of the present invention also statistically collapses large amounts of data, eliminates unneeded data, and recursively processes new data. The forecasts are compared to actual performance data, which may be graphically displayed or printed. A specific type of data is not important for the present invention, and those skilled in the art will understand that a wide variety of data may be used in the present invention. For example, the present invention contemplates any data that may be collected and verified over time. These data include, for example, Internet metering data, marketing data on the success

or failure of product offerings, telephone usage patterns, cash flow analyses, financial data, customer survey data on product reliability, customer survey data on product preference, etc.

The system and method operate within a computing platform. In one embodiment, the computing platform may be a multiple virtual storage (MVS) computing platform. In another embodiment, the computing platform may be a UNIX computing platform. In other embodiments, the computing platforms may be disk operating system (DOS) computing platforms. Those skilled in the art will appreciate that a variety of computing platforms may be used to implement the present invention.

The computing platform includes at least one resource whose performance is forecast. In one embodiment, the computing platform resource may be a central processing unit (CPU). In another embodiment, the computing platform resource may be a memory storage unit. In other embodiments, the computing platform resource may be a printer, a disk, or a disk drive unit. A specific computing platform resource is not important for the present invention, and those skilled in the art will understand that a number of resources may be used in the present invention.

Each resource includes at least one aspect. The aspect may be a performance metric. The performance metric may be resource utilization. "Utilization" is defined generally herein as the percentage that a particular computing platform resource is kept busy. Utilization is often termed "consumption".

In another embodiment, the performance metric may be resource efficiency or resource redundancy. "Efficiency" is defined generally herein as the measure of the useful portion of the total work performed by

the resource. "Redundancy" is defined generally herein as the measure of the increase in the workload of a particular resource. Of course, those skilled in the art will appreciate that a particular performance metric is not required by the present invention. Instead, a number of performance metrics may be used.

In one embodiment, the computing platform includes a resource manager. The resource manager collects performance data from its associated resource. The performance data is associated with a performance metric. In one embodiment, the resource manager collects performance data representing a CPU utilization performance metric.

The resource manager collects the performance data in regular intervals. In one embodiment, regular intervals include one-second intervals, for example. That is, in this embodiment, the resource manager collects performance data from its associated computer(s) every second. The interval size in which performance data is collected may be determined by the particular use for the performance metric, the particular resource, the particular computing platform, etc.

The computing platform also includes a plurality of statistical collapsers that statistically collapse the performance data into a series. In one embodiment, the series may be a time series representing a performance metric. A "time series" is defined generally herein as any ordered sequence of observations. Each observation represents a given point in time and is thus termed a "time point". Accordingly, a time series includes at least one time point.

A first statistical collapser generates a first time series representing a performance metric as though its associated performance data had been

collected at a first interval. The first time series includes a first set of time points. In one embodiment, the first statistical collapser generates a time series representing a performance metric as though its associated performance data had been collected in fifteen minute intervals. Accordingly, the time series includes four time points for each hour. In another embodiment, the first statistical collapser generates a time series representing a performance metric as though its associated performance data had been collected hourly. Accordingly, the time series includes one time point for each hour. It will be understood by persons skilled in the relevant art that the present invention encompasses statistical collapsers that generate time series representing performance metrics as though their associated performance data had been collected at any of a variety of suitable intervals. The interval size and corresponding number of time points generated by the first statistical collapser may be determined by the particular use for the performance metric, the particular resource, the particular computing platform, etc.

The computing platform also includes a database that stores data. In one embodiment, the database stores the time series representing the performance metric as though its associated performance data had been collected at fifteen-minute intervals.

The computing platform also includes a data extractor to extract data from the database. According to one embodiment, the data extractor extracts from the database the time series representing the performance metric as though its associated performance data had been collected at fifteen minute intervals.

The computing platform also includes a second statistical collapser. The second statistical collapser statistically collapses the first time

series, producing a second time series. The second time series includes a second set of time points. In one embodiment, the second statistical collapser statically collapses the fifteen minute time series into a one-week series. That is, the second statistical collapser generates a time series representing a performance metric an though its associated performance data had been collected weekly. Accordingly, the time series includes approximately four time points for each month. In another embodiment, the second statistical collapser generates a time series representing a performance metric as though its associated performance data had been collected daily. The corresponding time series includes approximately thirty time points for each month. I will be understood by persons skilled in the relevant art that the second statistical collapser may generate time series representing a performance metric as though its performance data had been collected at any of a variety of suitable intervals. As described above with reference to the first statistical collapser, the interval size and corresponding number of time points generated by the second statistical collapser may be determined by the particular use for the performance metric, the particular resource, the particular computing platform, etc.

The computing platform also includes a time series analyzer to determine whether the second time series is statistically stationary. The time series analyzer uses a plurality of X^2 (chi-square) tests to make this determination. The time series analyzer also evaluates autocorrelation statistics and autocovariance statistics. If the time series analyzer determines that the time series is statistically nonstationary, which is likely the case, then the time series analyzer converts the statistically nonstationary time series to

a statistically stationary time series by differencing each time point in the time series. The statistically stationary time series now represents the differenced values of performance data.

The computing platform also includes a time point converter. If the time series is already statistically stationary or after the time series analyzer converts the time series to statistical stationarity, the time point converter applies a statistical data set to the time series. Recall that the time series represents the performance metric as though its associated performance data had been collected from the computing platform at regular intervals. As such, the time series includes information indicating the time that the performance data was collected. In one embodiment, this information incudes a date/time stamp. That is, each data point in the time series includes a date/time stamp. The statistical data set converts each date/time stamp in the time series into a value representing a decimal number equivalent to the date/time stamp.

One feature of the present invention is an autoregressive modeling tool, which is applied to the converted time series to forecast a particular aspect of the computing platform. The autoregressive modeling tool is chosen by calculating autocorrelation, inverse autocorrelation, and partial autocorrelation functions, and by comparing these functions to theoretical correlation functions of several autoregressive constructs. In particular, one embodiment applies a first order mixed autoregressive construct, such as an autoregressive moving average (ARMA) construct, to the differenced time series. Another embodiment applies an autoregressive integrated moving average (ARIMA) construct to the differenced time series. In the

embodiment where the performance metric is resource utilization and the resource is a CPU, the resulting autoregressive modeling tool reliably forecasts CPU consumption with a ninety-five percent accuracy, provides an upper ninety-five percent confidence level, and provides a lower ninety-five percent confidence level. Conventional systems and methods that rely on linear regression or multivariable regression techniques may carry a lower confidence level.

Another feature of the present invention is that it uses empirical data as inputs to the autoregressive modeling tool. Using empirical data rather than causal variables provides more accurate forecasts. In the embodiment where the performance metric is resource utilization and the resource is a central processing unit, the empirical data is actual historical performance data, including logical CPU utilization information as well as physical CPU utilization information. Moreover, the system and method generate recursive forecasts whereby actual future performance data is fed back into the autoregressive modeling tool to calibrate the autoregressive modeling tool.

The computing platform includes a results processor, which generates graphical representations of a performance metric. The results processor also generates information for use in written reports that document the results of the forecasting process. The graphical and textual representations demonstrate the greater accuracy and reliability the present invention provides over conventional forecasting systems and methods.

In one embodiment, the results processor may be a graphical display unit, such as a computer display screen. In another embodiment, the results processor may be a textual display unit, such as a printer. In

the embodiment where the performance metric is resource utilization and the resource is a central processing unit, the results processor produces reports and graphical representations of comparisons of actual CPU utilization with CPU utilization forecasts.

Further features and advantages of the present invention as well as the structure and operation of various embodiments are described in detail below.

The present invention is best understood by reference to the figures, wherein references with like reference numbers indicate identical or functionally similar elements. In addition, the left-most digits refer to the figure in which the reference first appears in the accompanying figures in which:

Fig. 1 is a high-level block diagram of a computer platform suitable for use in an embodiment of the present invention;

Fig. 2 is a more detailed depiction of the block diagram of the computer platform of Fig. 1;

Fig. 3 is a more detailed depiction of the block diagram of the computer platform of Fig. 2;

Fig. 4 shows a flowchart of a forecasting process suitable for use in an embodiment of the present invention; and

Fig. 5 graphically depicts the comparisons of actual CPU utilization with CPU utilization forecasts which may be produced by one embodiment of the present invention.

A computer platform, and in particular, a system and method for forecasting computer platform resource performance is described herein. In the following description, numerous specific details, such as specific statistical symbols and relationships, specific methods of analyzing and processing computer performance data, etc., are set forth in order to

provide a full understanding of the present invention. One skilled in the relevant art, however, will readily recognize that the present invention can be practiced without one or more of the specific details, or with other methods, etc. In other instances, well-known structures or operations are not shown in detail in order to avoid obscuring the present invention.

For illustrative purposes, embodiments of the present invention are sometimes described with respect to a system and method for forecasting computer platform resource performance. It should be understood that the present invention is not limited to these embodiments. Instead, the present invention contemplates any data that may be collected and verified over time. These data may include, for example, Internet metering data, marketing data on the success or failure of product offerings, telephone usage patterns, cash flow analyses, financial data, customer survey data on product reliability, customer survey data on product preference, etc.

I. Example Environment:

Fig. 1 is a high-level block diagram of a computing platform **100** suitable for implementing an embodiment of the present invention. In this embodiment, the computer platform **100** is a multiple virtual storage (MVS) platform available from International Business Machines (IBM), or equivalent platform available from Amdahl and Hitachi Data Systems. In another embodiment, the computing platform **100** may be a UNIX computing platform. In other embodiments, the computing platform **100** may be a disk operating system (DOS) or a personal computer disk operating system (PC-DOS) computing platform. Those skilled in the art will appreciate that a variety of

computing platforms may be used to implement the present invention.

The computing platform **100** includes a computing network **102**. Typically, the computing network **102** may be a manufacturing facility, a telecommunications network, a multinational corporation, a financial institution, or a university, for example, that operates in a client-server environment. In that instance, the computer network **102** may connect "client" systems with "server" systems so that the server systems may perform a computation, retrieve a file, or search a database for a particular entry in response to a request by the client system. It is not uncommon for the client system to subsequently translate the response from the server system into a format that a human can understand.

To illustrate, suppose that the computing network **102** supports a bank. The bank has customer financial records, including personal bank account information stored in a large database. The personal bank account database acts as a server. The bank also provides access to its personal account database by certain client systems. For example, one client system may include a large number of point-of-sale cash registers or gas pump bank card readers. As a customer with a bank account at the bank attempts to purchase merchandise or gas using her bank card, the point-of-sale cash register or gas pump bank card reader accesses the customer's bank account information stored in the database. The point-of-sale cash register or gas pump bank card reader acting as a client system requests a determination from the bank personal account database of whether the customer has funds to cover the purchase price. The database responds accordingly, and the purchase is either authorized or refused. A

particular type of client-server environment is not essential to the present invention. It will be apparent to those skilled in the art that the exemplary embodiment may be implemented in other client-server environments, such as an airline flight reservation system, a mail-order facility, etc.

In one embodiment, the computing network **102** includes a plurality of computers **106**, as represented by computers **106a-106d**. For ease of explanation, however, the various embodiments generally are described with respect to only one computer **106**. Moreover, although an embodiment is sometimes described in the context of a large complex of distributed computers, the present invention is not limited to this embodiment. For example, the computers **106** may be arranged in a local area network (LAN) configuration in a building or in a group of buildings within a few miles of each other. Alternatively, the computers **106** may be located in a wide area network (WAN) configuration, wherein the computers **106** are linked together but geographically separated by great distances. The computers **106** may also be stand-alone devices not necessarily in communication with each other. The computer **106** in one embodiment is a mainframe computer available from IBM or equivalent mainframe computer available from Amdahl and Hitachi Data Systems. Alternatively, the computer **106** may be a high-performance workstation. Alternatively still, the computer **106** may be a personal computer.

The computing platform **100** includes at least one resource. In one embodiment, the computing platform resource may be a central processing unit (CPU). In another embodiment, the computing platform resource may be a memory storage unit. In other embodiments, the computing platform resource may be a

printer, a disk, or a disk drive unit. While a specific computing platform resource is not important for the present invention, those skilled in the art will understand that any number of resources can be used in the present invention.

Each resource includes at least one aspect. The aspect may be a performance metric. In one embodiment the performance metric may be resource utilization. Utilization is the measure of the percentage that a particular computing platform resource is kept busy, and is sometimes termed consumption. In another embodiment, the performance metric may be resource efficiency, which is defined as the measure of the useful portion of the total work performed by resource. In another embodiment, the performance metric may be resource redundancy, which is defined as the measure of the increase in the workload of a particular resource. Of course, those skilled in the art will appreciate that a particular performance metric is not required by the present invention. Instead, the present invention supports any of a number of performance metrics.

Fig. 2 is a more detailed block diagram of the computing platform **100** according to one embodiment. As illustrated, each computer **106** includes a resource manager **202**. Each resource manager **202** collects performance data from its associated resource. The performance data is associated with a performance metric. According to one embodiment, the resource manager **202** is a resource management facility (RMF) available with the multiple virtual storage (MVS) operating system that is running on the IBM mainframe computer as noted above or an equivalent mainframe computer available from Amdahl and Hitachi Data Systems. According to this embodiment, the resource

manager **202** extracts historical performance data from a processor resource/systems manager (PR/SM) (not shown) of the computer **106**. This historical computer performance data represents the CPU utilization and is equivalent to performance metering data obtained by real-time monitors. Thus, the CPU utilization information collected by the resource manager **202** are CPU utilization records that contain CPU activity measurements.

The resource manager **202** collects the performance data from the computer **106** at regular intervals. According to an exemplary embodiment, the regular intervals are one-second intervals. That is, according to the exemplary embodiment, the resource manager collects CPU workload performance data every second from computer **106**. In this way, the resource manager **202** provides the percent busy for each computer **106** each second in time. The interval size in which performance data is collected may be determined by the particular use of the performance metric, the particular resource, the particular computing platform, etc.

Because the computers **106** typically are maintained by large entities, the amount of data collected usually is quite large. Consequently, the data must be reduced to a manageable level. Statistically collapsing the one-second records generated by the resource manager **202** serves this purpose. The computing platform **100** thus also includes a plurality of statistical collapsers that statistically collapse the performance data into time series representing a performance metric. A "time series" is defined herein generally as any ordered sequence of observations. Each observation represents a given point in time and is thus termed a "time pont".

A statistical collapser averages a series of time points and generates a time series representing a performance metric as though its associated performance data had been collected at a particular interval. The resulting time series contains a set of time points commensurate with the representative collection interval.

According to one embodiment, the computing platform **100** includes a statistical collapser **204** that statistically collapses the performance data collected by the resource manager **202** into a time series. The statistical collapser **204** generates a time series representing performance data as though it had been collected at fifteen-minute intervals. Accordingly, the time series would include four time points for each hour. In another embodiment, the first statistical collapser generates a time series representing a performance metric as though its associated performance data had been collected hourly. Accordingly, the time series would include one time point for each hour.

Thus, the statistical collapser **204** statistically collapses the CPU utilization records generated every second by the resource manager **202** into CPU utilization records representing fifteen-minute intervals. Nine hundred original CPU utilization records ([60 seconds/minutes]x[15 minutes]=900) are averaged to produce one collapsed time point. The statistical collapser **204** calculates the mean for all metering records collected by the resource manager **202**, as described in greater detail below. The statistical collapser **204** then determines the median for each mean at fifteen-minute intervals. The time series generated by the statistical collapser **204** thus consists of four data points (or time points) per hour representing the mean CPU utilization percentage. It will be understood

by persons skilled in the relevant art that the present invention encompasses statistical collapsers that generate time series representing performance metrics as though its associated performance data had been collected at any of a variety of suitable intervals. The interval size and corresponding number of time points generated by the statistical collapser may be determined by the particular use of the performance metric, the particular resource, the particular computing platform, etc.

A stochastic process, such as the time series representing the performance metric as though its performance data had been collected at fifteen-minute intervals, may be represented by $Z(\omega,t)$. As used herein, a stochastic process is generally a family of time indexed random variables, $Z(\omega,t)$, where ω belongs to a sample space and t belongs to a time index set. That is, for a fixed time t, $Z(\omega,t)$ is a random variable. For a given ω, $Z(\omega,t)$, as a function of time, t, is called a sample function or realization. Thus, a time series is a realization or sample function from a certain stochastic process. Typically, however, the variable ω is suppressed, and the process is written $Z(t)$ or Z_t. The process is then called a real-valued process because it assumes only real values. The imaginary value, ω, is not treated. Moreover, for any given real-valued process $\{Z(\omega, t): t=0, \pm1, \pm2...\}$, the mean function of the process is given by $\mu_t=e(Z_{ft})$, which may be used by the statistical collapser **204** to calculate the mean for all metering records collected by the resource manager **202**.

The computing platform also includes a database **206** that stores data. In one embodiment, the database **206** stores the time series representing a performance metric as though its associated performance

data had been collected at fifteen-minute intervals. That is, after the resource manager **202** collects the performance data from the computers **106** and after the statistical collapser **204** generates the time series representing performance data collected at fifteen-minute intervals, the database **206** stores the time series.

The database **206**, in one embodiment, is capable of storing at least sixty gigabytes of performance data and can process at least one record per second. For example, the database **206** stores thousands of mainframe computer performance statistical descriptors and resource utilization data. Although the database **206** is depicted as a single database, according to the exemplary embodiment, the database **206** may be a plurality of databases. A database suitable for implementing the database **206** is a MICS database available from Computer Associates located in Santa Clara, California, or an SAS IT Service Vision database available from SAS Institute located in Cary, North Carolina.

The computing platform also includes a data extractor **208** to extract data from the database **206**. According to an exemplary embodiment, the data extractor **208** extracts from the database **206** the time series representing a performance metric as though its associated performance data had been collected at fifteen minute intervals.

Because the statistically collapsed data stored in the database **206** representing nine hundred original CPU utilization records still may be unwieldy, it may be reduced to a more manageable level. The computing platform **100** thus includes a second statistical collapser **210**. In general, the second statistical collapser **210** statistically collapses the

first time series, producing a second time series. The second time series incudes a second set of time points. In one embodiment, the second statistical collapser **210** statistically collapses the fifteen minute time series into a one-week time series. That is, the second statistical collapser **210** averages the fifteen minute time series and generates a time series representing a performance metric as though its associated performance data had been collected weekly. Accordingly, the time series includes approximately four time points for each month.

In another embodiment, the second statistical collapser **210** averages the fifteen minute time series and generates a time series representing the performance metric as though its associated performance data had been collected daily. Accordingly, the time series includes approximately thirty time points for each month. It will be understood by persons skilled in the relevant art that the second statistical collapser **210** may generate time series representing performance data as though it had been collected at any of the variety of suitable intervals.

It must be noted that if a time series contains too few time points, the time series may not be representative of the particular data under analysis, including, but not limited to Internet metering data, marketing data on the success or failure of product offerings, telephone usage patterns, cash flow analyses, financial data, customer survey data and product reliability, customer survey data on product preference, etc. For example, if the time series in the above example embodiment contains too few time points, the time series may not be representative of actual resource performance. That is, peak usages (or spikes) may not be detected if too few time points are

taken. Therefore, sampling intervals which exclude such peaks may inaccurately represent the resource utilization. Thus, the number of time points in the time series may be determined by the particular use of the performance metric, the particular resource, the particular computing platform, etc. To illustrate, suppose a network manager that is responsible for monitoring the behavior and effectiveness of the computing platform **100** resources monitors the performance and activities for each computer **106**. The system network manager tracks the computing platform **100** resources performances by gathering the appropriate performance data from each component or network element in the computing platform **100**. As described, performance metrics to be monitored include, but are not limited to, CPU consumption percentage, disk drive usage percentage, Internet traffic, users logged on to the Internet, network communication packet traffic, and users logged on to a particular server computer, for example.

Suppose further that the computing network **102** typically includes entities such as a configuration management team and a performance management team. The configuration management team would plan the computing platform **100's** growth and modernization. Accordingly, weekly data points would be adequate for these network planning purposes. Daily data points may be more appropriate for use by the performance management team, however. This is because the performance management team would be concerned with maintaining the computing platform **100's** error-free performance. Accordingly, the performance management team would be concerned about peak usages (or spikes) in resource consumption of the computing platform **100**. Monitoring spikes in

the computing platform **100** would facilitate load sharing, for example.

Referring to Fig. 3, one embodiment of the present invention generates accurate CPU utilization descriptors in the following manner. The resource manager **202** for the computer **106** collects the performance data **301** and provides it in the form of one-second metering records **302** to the statistical collapser **204**. The statistical collapser **204** statistically collapses the one-second records **302** into fifteen-minute data, which is stored in a file of performance data **304** of the database **206**. The data extractor **208** extracts the performance data **304** from the database **206** and provides it to the statistical collapser **210**. The statistical collapser **210** statistically collapses the fifteen-minute data into one-week data.

As described above, the records **302** are metering records for PR/SM computers. Accordingly, the records **302** include both a percentage logical processor busy variable "LPCPCSSU" from a PR/SM LPAR configuration file from the computer **106**, as well as a percentage CPU busy variable "CPU PCBSY" from the computer **106** hardware utilization CPU activity file, which variables are well-known. According to one embodiment, a set of one-week records **306** represents ([4 records/hour]x[10 hours/day]x[5 days/week]=200) two hundred records. The four records per hour variable represents four time points. The ten hours per day variable represents a prime ten hour operating shift for the computing platform **100**. The five days per week variable represents a prime operating work week for the computing platform **100**. In other words, the one-week interval records **306** are each a collapse of two hundred

fifteen-minute interval records stored in the file **304** of the database **206**.

Recall that a time series analogous to the one-week interval data resulted from collapsing the fifteen-minute interval data. According to the constraints of one embodiment, this time period must be statistically stationary. A statistically stationary time series is generally regarded as a time series which as a stochastic process, as defined above, is unchanged by a uniform increment in the time parameter defining the time series.

It must be noted that few time series are statistically stationary. The computing platform **100** thus includes a time series analyzer **212** to determine whether the time series generated by the statistical collapser **210** is statistically stationary. According to one embodiment, the time series analyzer **212** analyzes probability values for a plurality of X^2 (chi-square) tests to make this determination. "Chi-square tests" as used herein generally define generalizations and extensions of a test for significant differences between a binomial population and a polynomial population, wherein each observation may fall into one of several classes and which furnishes a comparison among several samples rather than just between two samples. Such chi-square tests include a test of residuals, tests of hypotheses, tests of significance, tests of homogeneity, tests of association, goodness of fit tests, etc., as is known in the relevant art. In the embodiment where the resource is computer **106** and the performance metric is CPU utilization, the time series analyzer **212** determines whether there is a statistically significant correlation between a particular CPU utilization value and the value for CPU utilization for the previous time period by reviewing

correlation and covariance statistics. Tables 1-4 list chi-square values for a test for residuals for the computers 106a-106d, respectively. The column "DF" refers to the degrees of freedom of variation among a set of scores. In particular, column "DF" refers to the degrees of freedom of variation among a set of metering records for CPU utilization. To illustrate, suppose there is a set of ten scores. Statistically the degrees of freedom given by

$$DF=n-1,$$

when n is the number of scores. Thus, with a set of ten scores, there would be nine degrees of freedom. In effect, nine sets of scores are free to vary statistically while one set is fixed in value.

Table 1

ChiSquare Values for the Autocorrelation Test of Residuals for the Computer 106a.

T_0 Lag	Chi-Square	DF	Prob.						
6	12.50	4	0.014	-0.071	0.172	-0.233	0.055	-0.027	0.340
12	16.53	10	0.085	0.112	-0.012	-0.008	-0.016	0.159	0.143
18	24.26	16	0.084	0.178	-0.166	-0.089	-0.169	0.034	-0.071
24	35.15	22	0.037	0.309	-0.041	-0.077	-0.104	-0.101	-0.011

Table 2

Chi Square Values for the Autocorrelation Test of Residuals for the Computer 106b.

T_0 Lag	Chi-Square	DF	Prob.	Auto correlations					
6	3.57	4	0.467	0.008	0.030	-0.019	-0.009	-0.173	-0.164
12	11.93	10	0.290	-0.206	0.046	-0.007	-0.148	0.043	0.235
18	15.70	16	0.474	0.065	-0.058	0.108	-0.080	-0.000	-0.148
24	21.22	22	0.507	0.050	0.044	-0.039	-0.074	0.213	0.024

Table 3

Chi Square Values for the Autocorrelation Test of Residuals for the Computer 106c.

T_0 Lag	Chi-Square	DF	Prob.	AUTO CORRELATION					
6	2.51	4	0.642	-0.086	-0.007	-0.080	0.132	-0.091	-0.054
12	5.15	10	0.881	-0.029	0.141	0.015	-0.110	-0.060	-0.055
18	8.45	16	0.934	-0.108	-0.062	-0.045	0.142	-0.049	0.051
24	14.05	22	0.900	0.083	0.049	-0.096	0.172	0.079	0.075

Table 4

Chi Square Values for the Autocorrelation Test of Residuals for the Computer 106d.

T_0 Lag	Chi-Square	DF	Prob.	AUTO CORRELATION					
6	3.04	4	0.551	-0.014	0.166	0.092	-0.088	-0.011	-0.089
12	6.39	10	0.781	-0.116	-0.021	0.035	-0.113	0.125	-0.078
18	7.65	16	0.959	-0.025	0.107	-0.014	-0.053	-0.037	-0.008
24	10.66	22	0.979	-0.037	-0.043	-0.029	0.003	0.141	-0.085

As described above, few time series are statistically stationary. Accordingly, the time series analyzer **212** confirms that the time series representing CPU consumption at one-week intervals are likewise not statistically stationary. That is, the time series analyzer **212** confirms that there is a statistically significant correlation between one value of CPU utilization and the value of CPU utilization for the previous time period.

Such correlation is undesirable according to the constraints of one embodiment because the time series thus contains statistical artifacts extraneous to the data represented by the time series. The correlation within the time series therefore should be broken. This is accomplished by differencing the time

analyzer **212** converts the time series to a statistically stationary time series by differencing each time point in the time series. The time series analyzer **212** averages the differences among the time points and then subtracts the averages from each time point. Thus, rather than modeling the CPU utilization per se, this embodiment models the differenced values of CPU utilization from one period to the next.

A differencing period must be determined that produces the most accurate forecast. The location of points selected, as well as the number of points selected from the time series when differencing determines how robust the resulting construct is. Tables 5-8 list weekly data points selected using one embodiment to represent CPU utilization for the computers **106a-106d**, respectively, in the "mean CPU busy" column.

Table 5

Week	Mean CPU Busy	Forecast	Lower 95% Confidence Level	Upper 95% Confidence Level
11 APR 96	98.91			
19 APR 96	98.92	98.51	82.82	114.2
25 APR 96	96.08	98.29	82.60	114.0
03 MAY 96	96.38	96.83	81.14	112.5
09 MAY 96	96.45	96.73	81.04	112.4
17 MAY 96	97.49	96.54	80.85	112.2
23 MAY 96	92.54	96.77	81.07	112.5
31 MAY 96	83.06	94.39	78.70	110.1
06 JUN 96	99.28	90.04	74.35	105.7
14 JUN 96	92.33	96.86	81.17	112.6
20 JUN 96	87.31	93.62	77.93	109.3
28 JUN 96	95.70	91.21	75.52	106.9
04 JUL 96	83.09	94.63	78.94	110.3

04 JUL 96	83.09	94.63	78.94	110.3
12 JUL 96	87.21	88.93	73.24	104.6
18 JUL 96	89.77	90.49	74.80	106.2
26 JUL 96	87.64	91.38	75.69	107.1
01 AUG 96	67.66	90.23	74.54	105.9
09 AUG 96	74.76	81.32	65.63	97.01
15 AUG 96	72.92	84.18	68.49	99.87
23 AUG 96	81.54	83.16	67.47	98.85
29 AUG 96	94.31	86.68	70.99	102.4
06 SEP 96	91.40	92.00	76.31	107.7
12 SEP 96	95.12	90.51	74.82	106.2
20 SEP 96	73.85	91.90	76.21	107.6
26 SEP 96	86.22	82.43	66.74	98.12
04 OCT 96	82.94	87.58	71.89	103.3
10 OCT 96	92.51	85.93	70.24	101.6
18 OCT 96	83.35	89.86	74.17	105.6
26 OCT 96	85.14	85.66	69.96	101.3
09 NOV 96	74.62	86.21	70.52	101.9
15 NOV 96	94.73	81.41	65.72	97.10
21 NOV 96	86.17	89.92	74.23	105.6
05 DEC 96	95.41	85.98	70.29	101.7
13 DEC 96	93.33	89.77	74.08	105.5
19 DEC 96	99.11	88.64	72.95	104.3
27 DEC 96	72.55	90.92	75.23	106.6
10 JAN 97	75.15	79.16	63.47	94.85
16 JAN 97	79.68	80.06	64.37	95.75
24 JAN 97	86.72	81.81	66.12	97.50
30 JAN 97	98.05	84.64	68.95	100.3
07 FEB 97	94.21	89.33	73.64	105.0
13 FEB 97	92.53	87.44	71.75	103.1
21 FEB 97	77.12	86.48	70.79	102.2
27 FEB 97	82.73	79.56	63.87	95.25

07 MAR 97	85.37	81.78	66.09	97.47
13 MAR 97	88.49	82.70	67.01	98.39
15 MAR 97	85.79	83.83	68.13	99.52
23 MAR 97	73.48	82.43	66.74	98.12
06 APR 97	70.25	76.86	61.17	92.55
12 APR 97	84.31	75.22	59.53	90.92
18 APR 97	82.00	81.11	65.42	96.80
26 APR 97	82.88	79.88	64.19	95.57
10 MAY 97	83.81	80.03	64.34	95.72
16 MAY 97	78.50	80.21	64.52	95.90
24 MAY 97	.	77.10	59.99	94.21
01 JUN 97	.	76.62	59.26	93.98
07 JUN 97	.	76.19	58.78	93.60
15 JUN 97	.	75.77	57.95	92.79
21 JUN 97	.	75.37	57.95	92.79
29 JUN 97	.	74.97	57.55	92.39
05 JUL 97	.	74.57	57.15	91.99
13 JUL 97	.	74.17	56.75	91.59
19 JUL 97	.	73.77	56.35	91.19
27 JUL 97	.	73.37	55.95	90.79
02 AUG 97	.	72.97	55.55	90.39
10 AUG 97	.	72.57	55.15	89.99
16 AUG 97	.	72.17	54.75	89.59
24 AUG 97	.	71.77	54.35	89.19

Table 6

Week	Mean CPU Busy	Forecast	Lower 95% Confidence Level	Upper 95% Confidence Level
11 APR 96	63.95	.	.	.
19 APR 96	66.24	64.11	45.16	83.06
25 APR 96	75.12	64.90	45.95	83.85
04 MAY 96	71.55	68.45	49.50	87.40
09 MAY 96	65.93	71.00	52.05	89.95
17 MAY 96	77.47	69.79	50.84	88.74
23 MAY 96	67.79	71.45	52.50	90.40
31 MAY 96	68.43	71.84	52.89	90.79
06 JUN 96	81.53	70.13	51.18	89.08
14 JUN 96	82.90	73.38	54.43	92.32
20 JUN 96	57.80	78.17	59.22	97.12
28 JUN 96	76.27	73.27	54.32	92.22
04 JUL 96	60.44	71.03	52.08	89.98
12 JUL 96	75.79	69.17	50.22	88.12
18 JUL 96	63.34	69.47	50.52	88.42
26 JUL 96	50.79	69.18	50.23	88.13
01 AUG 96	64.23	62.60	43.65	81.54
09 AUG 96	76.07	60.74	41.79	79.69
15 AUG 96	72.50	66.28	47.33	85.23
23 AUG 96	82.89	70.44	51.49	89.39
29 AUG 96	90.05	74.80	55.85	93.75
06 SEP 96	91.40	81.30	62.35	100.3
12 SEP 96	87.72	86.40	67.45	105.4
20 SEP 96	77.73	88.06	69.11	107.0
26 SEP 96	86.24	85.08	66.13	104.0
04 OCT 96	80.41	84.04	65.09	103.0
10 OCT 96	83.86	83.61	64.66	102.6
18 OCT 96	74.61	83.19	64.24	102.1

26 OCT 96	85.73	80.95	62.00	99.90
09 NOV 96	76.62	81.21	62.26	100.2
15 NOV 96	86.86	81.00	62.05	99.94
21 NOV 96	90.89	82.00	63.05	101.0
05 DEC 96	92.88	85.90	66.95	104.9
13 DEC 96	85.18	89.26	70.31	108.2
19 DEC 96	88.12	89.00	70.05	108.0
27 DEC 96	58.33	88.10	69.15	107.1
10 JAN 97	90.47	79.37	60.42	98.32
16 JAN 97	70.97	78.36	59.41	97.31
24 JAN 97	77.50	78.94	59.99	97.89
30 JAN 97	78.22	76.98	58.03	95.93
07 FEB 97	85.71	77.65	58.70	96.60
13 FEB 97	83.08	80.38	61.43	99.33
21 FEB 97	71.57	82.52	63.57	101.5
27 FEB 97	86.93	79.55	60.60	98.50
07 MAR 97	83.41	80.24	61.29	99.19
13 MAR 97	96.19	82.82	63.87	101.8
15 MAR 97	88.15	87.15	68.20	106.1
23 MAR 97	79.12	89.58	70.63	108.5
06 APR 97	87.12	86.32	67.37	105.3
12 APR 97	84.95	85.20	66.25	104.1
18 APR 97	66.50	85.73	66.78	104.7
26 APR 97	70.25	79.98	61.03	98.93
10 MAY 97	76.15	74.35	55.40	93.30
16 MAY 97	72.97	74.20	55.25	93.15
24 MAY 97	.	74.32	54.53	94.10
01 JUN 97	.	74.53	54.98	96.08
07 JUN 97	.	74.67	51.72	97.63
15 JUN 97	.	74.83	50.50	99.16
21 JUN 97	.	74.99	49.37	100.6
29 JUN 97	.	75.14	48.29	102.0

05 JUL 97	.	75.30	47.27	103.3
13 JUL 97	.	75.45	46.30	104.6
19 JUL 97	.	75.61	45.37	105.9
27 JUL 97	.	75.77	44.48	107.1
02 AUG 97	.	75.92	43.62	108.2
10 AUG 97	.	76.08	42.79	109.4
16 AUG 97	.	76.23	41.99	110.5
24 AUG 97	.	76.39	41.22	111.6

Table 7

Week	Mean CPU Busy	Forecast	Lower 95% Confidence Level	Upper 95% Confidence Level
11 APR 96	74.48	.	.	.
19 APR 96	88.23	74.76	62.31	87.20
25 APR 96	75.57	76.10	63.66	88.54
03 MAY 96	84.13	75.35	62.91	87.80
09 MAY 96	73.61	76.29	63.84	88.73
17 MAY 96	79.35	75.71	63.27	88.16
23 MAY 96	76.92	76.42	63.98	88.87
31 MAY 96	66.06	76.48	64.04	88.93
06 JUN 96	83.72	75.88	63.44	88.33
14 JUN 96	82.94	77.53	65.09	89.98
20 JUN 96	79.62	77.73	65.28	90.17
28 JUN 96	75.31	77.72	65.28	90.16
04 JUL 96	70.35	77.64	65.19	90.08
12 JUL 96	73.26	77.50	65.06	89.94
18 JUL 96	86.43	77.98	65.54	90.43
26 JUL 96	77.94	79.28	66.84	91.73
01 AUG 96	69.34	78.87	66.42	91.31
09 AUG 96	79.64	78.44	66.00	90.89
15 AUG 96	79.90	79.51	67.07	91.96

23 AUG 96	79.81	79.79	67.34	92.23
29 AUG 96	85.81	80.04	67.59	92.48
06 SEP 96	79.79	80.77	68.32	93.21
12 SEP 96	84.82	80.55	68.10	92.99
20 SEP 96	86.84	81.20	68.76	93.64
26 SEP 96	89.07	81.61	69.17	94.06
04 OCT 96	84.71	82.05	69.60	94.49
10 OCT 96	88.20	81.96	69.51	94.40
18 OCT 96	80.48	82.49	70.04	94.93
26 OCT 96	83.67	82.13	69.69	94.58
09 NOV 96	78.33	82.64	70.20	95.09
15 NOV 96	90.33	82.48	70.03	94.92
21 NOV 96	80.22	83.68	71.24	96.12
05 DEC 96	91.71	83.14	70.69	95.58
13 DEC 96	87.36	84.30	71.86	96.74
19 DEC 96	89.50	84.21	71.77	96.66
27 DEC 96	63.88	84.64	72.19	97.08
10 JAN 97	82.33	82.87	70.42	95.31
16 JAN 97	81.46	84.58	72.14	97.03
24 JAN 97	78.47	84.77	72.32	97.21
30 JAN 97	83.23	84.79	72.34	97.23
07 FEB 97	92.31	85.42	72.98	97.86
13 FEB 97	93.73	86.39	73.95	98.84
21 FEB 97	81.92	86.76	74.32	99.21
27 FEB 97	84.39	86.08	73.64	98.53
07 MAR 97	90.97	86.53	74.09	98.98
13 MAR 97	89.53	87.31	74.87	99.75
15 MAR 97	82.45	87.45	75.01	99.90
23 MAR 97	84.13	87.15	74.70	99.59
06 APR 97	89.94	87.54	75.09	99.98
12 APR 97	94.17	88.25	75.81	100.7
18 APR 97	87.39	88.84	76.40	101.3

26 APR 97	77.43	88.56	76.12	101.0
10 MAY 97	92.78	88.03	75.58	100.5
16 MAY 97	83.43	89.50	77.05	101.9
24 MAY 97	.	89.71	77.23	102.2
01 JUN 97	.	90.02	77.54	102.5
07 JUN 97	.	90.30	77.82	102.8
15 JUN 97	.	90.58	78.10	103.1
21 JUN 97	.	90.86	78.37	103.3
29 JUN 97	.	91.14	78.65	103.6
05 JUL 97	.	91.41	78.93	103.9
13 JUL 97	.	91.69	79.21	104.2
19 JUL 97	.	91.97	79.49	104.5
27 JUL 97	.	92.25	79.76	104.7
02 AUG 97	.	92.52	80.04	105.0
10 AUG 97	.	92.80	80.32	105.3
16 AUG 97	.	93.08	80.60	105.6
24 AUG 97	.	93.36	80.87	105.8

Table 8

Week	Mean CPU Busy	Forecast	Lower 95% Confidence Level	Upper 95% Confidence Level
11 APR 96	93.60	.	.	.
19 APR 96	97.86	93.68	86.00	101.4
25 APR 96	94.98	93.77	86.09	101.4
03 MAY 96	94.77	93.83	86.16	101.5
09 MAY 96	95.67	93.91	86.24	101.6
17 MAY 96	99.23	93.99	86.31	101.7
23 MAY 96	94.32	94.07	86.40	101.7
31 MAY 96	85.44	94.14	86.46	101.8
06 JUN 96	95.34	94.19	86.52	101.9
14 JUN 96	96.71	94.29	86.62	102.0
20 JUN 96	92.43	94.37	86.70	102.0
28 JUN 96	98.80	94.44	86.76	102.1
04 JUL 96	88.92	94.53	86.86	102.2
12 JUL 96	96.01	94.58	86.91	102.3
18 JUL 96	96.69	94.68	87.00	102.4
26 JUL 96	94.49	94.75	87.08	102.4
01 AUG 96	96.60	94.82	87.15	102.5
09 AUG 96	98.36	94.91	87.23	102.6
15 AUG 96	93.94	94.99	87.31	102.7
23 AUG 96	98.03	95.05	87.38	102.7
29 AUG 96	98.24	95.14	87.47	102.8
06 SEP 96	92.10	95.22	87.54	102.9
12 SEP 96	94.35	95.28	87.60	102.9
20 SEP 96	98.32	95.36	87.68	103.0
26 SEP 96	98.61	95.45	87.77	103.1
04 OCT 96	98.67	95.52	87.85	103.2
10 OCT 96	99.89	95.60	87.92	103.3
18 OCT 96	98.23	95.68	88.00	103.4

26 OCT 96	98.88	95.75	88.08	103.4
09 NOV 96	98.58	95.83	88.15	103.5
15 NOV 96	99.04	95.90	88.23	103.6
21 NOV 96	98.47	95.98	88.31	103.7
05 DEC 96	96.49	96.06	88.38	103.7
13 DEC 96	93.85	96.13	88.45	103.8
19 DEC 96	98.21	96.20	88.52	103.9
27 DEC 96	78.54	96.28	88.61	104.0
10 JAN 97	95.92	96.31	88.63	104.0
16 JAN 97	91.43	96.43	88.76	104.1
24 JAN 97	97.56	96.49	88.82	104.2
30 JAN 97	97.89	96.59	88.91	104.3
07 FEB 97	95.20	96.66	88.99	104.3
13 FEB 97	100.0	96.73	89.06	104.4
21 FEB 97	99.01	96.82	89.15	104.5
27 FEB 97	95.94	96.90	89.22	104.6
07 MAR 97	95.01	96.96	89.29	104.6
13 MAR 97	99.24	97.04	89.36	104.7
15 MAR 97	90.65	97.13	89.45	104.8
23 MAR 97	97.45	97.18	89.51	104.9
06 APR 97	98.57	97.27	89.60	104.9
12 APR 97	98.83	97.35	89.68	105.0
18 APR 97	99.37	97.43	89.76	105.1
26 APR 97	97.03	97.51	89.83	105.2
10 MAY 97	97.79	97.58	89.90	105.3
16 MAY 97	94.33	97.66	89.98	105.3
24 MAY 97	.	97.81	90.13	105.5
01 JUN 97	.	97.89	90.21	105.6
07 JUN 97	.	97.96	90.29	105.6
15 JUN 97	.	98.04	90.36	105.7
21 JUN 97	.	98.11	90.44	105.8
29 JUN 97	.	98.19	90.52	105.9

05 JUL 97	.	98.27	90.59	105.9
13 JUL 97	.	98.34	90.67	106.0
19 JUL 97	.	98.42	90.75	106.1
27 JUL 97	.	98.50	90.82	106.2
02 Aug 97	.	98.57	90.90	106.2
10 AUG 97	.	98.65	90.98	106.3
16 AUG 97	.	98.73	91.05	106.4
24 AUG 97	.	98.80	91.13	106.5

As described above, the statistically stationary time series generated by the time series analyzer **212** represents performance data that is collected from the computer platform **100** at regular intervals. As such, the time series includes information indicating the time that the performance data was collected from the computers **106**. In one embodiment, each data point in the time series includes a date/time stamp. Note that Tables 5-8 include a date/time stamp in the "week" column. The date/time stamp provided takes a form that in one embodiment is not as compatible with the system and method as desired and therefore must be converted to a more usable form. According to one embodiment, the computing platform **100** includes a time point converter **214**, which utilizes a data set and converts the time series date/time stamp to a number of seconds equivalent to the value represented by the date/time stamp under the data set. A data set suitable for implementing the time point converter **214** is available from SAS in Cary, North Carolina, which converts a date/stamp to a decimal number.

One feature of the system and method is an autoregressive modeling tool **216**. In one embodiment,

the autoregressive modeling tool 216 is applied to the statistically stationary time series representing a performance metric as though its performance data had been collected in weekly intervals to forecast the performance of the computing platform 100. The autoregressive modeling tool 216 is selected by calculating autocorrelation, inverse autocorrelation, and partial autocorrelation functions, and comparing these functions to theoretical correlation functions expected from various autoregressive constructs.

For example, in a process, if only a finite number of π rates are non-zero, i.e., $\pi_1=\phi_1, \pi_2=\phi_2, \ldots \pi_p=\phi_p$ and $\pi_k=0$, for $k > p$, then the process is generally considered an autoregressive model of order p, which is denoted as AR(p). An autoregressive model of order p is given by

$$\tilde{Z}_t = \phi_1 \tilde{Z}_{t-1} \ldots + \phi_p \tilde{Z}_{t-p} + a_t \quad \text{or} \quad \phi_p(B)\tilde{Z}_t = a_2,$$

where $\phi_p(B)=(1-\phi_1 B-\ldots 1-\phi_p B^p)$. Thus, the autoregressive modeling tool 216 takes the times series, Z_t, and regresses the value of Z at time t on its own past values plus a random shock value, i.e., $Z_t=\pi_1+\pi_2\ Z_{t-2}+\ldots+\alpha_t$ or equivalently, $\pi(B)Z_t=\alpha_t$ where

$$\pi(B) = 1 - \sum_{j=1}^{\infty} \pi_j B^j, \text{ and } 1 + \sum_{j=1}^{\infty} |\pi j| < \infty.$$

The autocorrelation function becomes $^{Pk=}\phi 1 Pk-1=^{\Phi}1^k$, where $k \geq 1$, and where $P_o=1$. The inverse autocorrelation function becomes

$$\rho_{k(I)} = \gamma \frac{\gamma_{k(I)}}{\gamma_{0(I)}} = \frac{1}{\gamma_{0(I)}} \int_{-\pi}^{\pi} f^{-1}(\omega) e^{i} k d\omega$$

and the partial autocorrelation function becomes

$$\phi_{kk} = \begin{cases} \rho_1 = \phi_1, & k=1 \\ 0, & for\ k \geq 2. \end{cases}$$

The resulting autoregressive modeling tool 216 may be a first order mixed autoregressive

construct. In particular, the autoregressive modeling tool **216** that the system and method apply to the time series may be an autoregressive integrated moving average (ARIMA) model to forecast the level of mean CPU utilization for each computer **106** over time. In another embodiment, the resultant autoregressive modeling tool **216** may be an autoregressive moving average (ARMA) model. These constructs predict a moving average parameter estimate divided by a coefficient of the lagged autoregressive value of CPU utilization for each computer **106** and its estimated value. These constructs also predict a random error. Table 9-12 list the regression estimates for the moving average parameters (MA) and the autoregressive parameters (AR) of the mean CPU utilization (MU) for the computers **106a-106d**, respectively. The column "T Ratio" indicates values for a "T" test of validity for a particular statistic. For example, the T Ratio indicate whether "t" values are less than or equal to a given level of confidence.

Table 9

Conditional Least Squares Estimation of the Time Series for the Computer 106a.

Parameter	Estimate	Random Error	T Ratio	Lag
MU	0.89907	0.17365	2.30	0
MA1, 1	0.51935	0.05436	18.40	1
AR1, 1	0.73434	0.04533	4.99	1

Constant Estimate = 0.2757353

Table 10

Conditional Least Squares Estimation of the Time Series for the Computer 106b.

Parameter	Estimate	Random Error	T Ratio	Lag
MU	0.75565	0.57312	0.27	0
MA1, 1	0.48501	0.19567	4.48	1
AR1, 1	0.71503	0.21807	7.99	1

Constant Estimate = 0.18911627

Table 11

Conditional Least Squares Estimation of the Time Series for the Computer 106c.

Parameter	Estimate	Random Error	T Ratio	Lag
MU	0.87759	0.09295	2.99	0
MA1, 1	0.99100	0.08170	12.24	1
AR1, 1	0.77904	0.15489	5.51	1

Constant Estimate = 0.25564741

Table 12

Conditional Least Squares Estimation of the Time Series for the Computer 106d.

Parameter	Estimate	Random Error	T Ratio	Lag
MU	0.77650	0.04372	1.75	0
MA1, 1	0.99240	0.06205	16.12	1
AR1, 1	0.83932	0.11828	6.02	1

Constant Estimate = 0.07628922

The autoregressive modeling tool 216 "fits the data" or matches the theoretical autocorrelation functions of different atuoregressive modeling constructs to the autocorrelation functions computed from the time series. The autoregressive modeling tool 216 thus forecasts CPU utilization with ninety-five percent accuracy, provides an upper ninety-five percent confidence level, and provides a lower ninety-five percent confidence level for all computers 106. This embodiment of the present invention is therefore advantageous over conventional systems and methods that rely on linear regression or multivariable regression techniques, which may carry a lower confidence level.

An ARIMA (1,1,1) construct in one embodiment forecasts the level of CPU utilization. This represents that the ARIMA construct has one (1) autoregressive term, one (1) nonseasonal difference, and one (1) lagged forecast error in its prediction equation,

$$\hat{Z}_t = \mu + Z(t-1) + \phi_1\left(Z(t-1) - Z(t-2)\right) - \theta_1 e(t-1),$$

where θ_1 is a moving average parameter and ϕ_1 is an autoregressive parameter. The ARIMA (1,1,1) construct for forecasting the level of CPU utilization is equivalent to an ARMA (1,1) construct, while forecasts the change in CPU utilization. The ARMA construct has one (1) autoregressive term, one (1) nonseasonal difference, and zero (0) lagged forecast errors in its prediction equation, $(1-\phi_1 B)Z_t=(1-\theta_1 B)\alpha_t$, where θ_1 is a moving average parameter, ϕ_1 is an autoregressive parameter, B is a backshift operator, and a_t is a zero mean white noise process. Accordingly, the autoregressive moving average for the computer 106a is given by $(1-B)\ cpubusy_t=0.89909+(1+0.51935\ B)/(1-0.73434\ B)\ a_t$. The autoregressive moving average for the computer 106b is given by (1-b)

$cpubusy_t=0.75565+(1+0.48501\ B)/(1-0.71503)\ a_t$. The autoregressive moving average for the computer **106c** is given by $(1-B)\ cpubusy_t=0.87759+(1+0.99100\ B)/(1-0.77904\ B)\ a_t$. The autoregressive moving average for the computer **106d** is given by $(1-B)\ cpubusy_t=0.77650+(1+0.99240\ B)/(1-0.83932\ B)\ a_t$.

II. Autoregressive Forecasting of Computing Resources:

Fig. 4 depicts a flow chart of a collecting, collapsing, and regressing process **400** suitable for use in one embodiment of the present invention. Task **402** starts the process **400**, where control immediately passes to task **404**. Task **404** extracts performance data from at least one of the computers **106**. In one embodiment, the resource manager **202** extracts the performance data from its associated computer every second.

Task **406** statistically collapses the performance data into a first time series. In one embodiment, the statistical colapser **204** generates a time series representing a performance metric as though its associated performance data had been collected at fifteen minute intervals. The database **206** then stores the fifteen minute time series. The data extractor **208** extracts the time series representing performance data collected at fifteen minute intervals from the database **206**.

Task **408** statistically collapses the first time series into a second time series. In one embodiment, the statistical collapser **210** generates a second time series representing performance data as though it had been collected weekly. Task **408** then determines whether the weekly time series is statistically stationary. If the time series is

statistically stationary, then task **408** writes the time series to the time point converter **214**.

If, on the other hand, the time series is statistically non-stationary, then task **410** converts the statistically non-stationary time series to a statistically stationary time series by differencing each time point, as explained above. After task **410** generates the statistically stationary time series, task **410** writes the converted time series to the time point converter **214**. The time point converter **214** converts the date/time stamp associated with each data point in the time series to an equivalent data point suitable for use in the autoregressive modeling tool **216**, as explained above.

Task **412** applies the autoregressive modeling tool **216** to the time series to generate forecasts of the computing platform **100** resources, Task **412** also generates recursive forecasts whereby actual future performance data is fed back into the autoregressive modeling tool **216** to calibrate the system and method. Task **414** completes the process **400**. This process provides a turnkey solution to CPU utilization forecasting that can be implemented easily by any system network manager.

Referring back to Fig. 1, the computing platform **100** may include a results processor **104**. The results processor **104** generates representations of performance data extracted from the computing platform **100**. The results processor **104** generates information for use in written reports that document the results of the process **400**. In the embodiment where the performance metric is resource utilization and the resource is a central processing unit of the computers **106**, the results processor **104** produces reports and

graphical representations of comparisons of actual CPU utilization with CPU utilization forecasts.

For example, Tables 5-8, above, are textual representations produced by the results processor **104**. Recall that Tables 5-8 represent the CPU utilization performance metric for the computers **106a-106d**, respectively. Tables 5-8 include a "forecast" column, a "lower 95% confidence level" column, and an "upper 95% confidence level" column.

Fig. 5 depicts an exemplary graphical representation produced utilizing one embodiment of the results processor **104**. The graphical representation **500** corresponds to the data contained in Table 1 above of CPU utilization for the computer **106a**. Graph **502** represents actual CPU utilization. Graph **504** represents forecast CPU utilization. Note that the Tables 5-8 and the graphical representation **500** illustrate that the forecast performance metric somewhat accurately represents actual CPU utilization.

Graph **506** represents the upper ninety-five percent confidence interval. This confidence interval provides an estimated range of values which is likely to include an unknown parameter. For example, for each weekly time point taken, ninety-five percent of the time points will include an unknown parameter. Graph **508** represents the lower ninety-five percent confidence interval. Note that the forecast values fall within the ninety-five percent confidence intervals. The graphical and textual representations demonstrate the greater accuracy and reliability which the present invention provides over conventional forecasting systems and methods.

Referring back to Fig. 1, in one embodiment, the results processor **104** is external to the computing network **102**, as represented by the results processor

104a. In an alternate embodiment, the results processor 104 is internal to the computing network 102, as represented by the results processor 104b.

The system and method may be implemented in computer software run on a computer. Alternately, the system and method may be implemented using hardware or a combination of hardware and software, and may be implemented in a computer system or other processing system. In an embodiment where the invention is implemented using software, the software may be stored on a computer program product (such as an optical disk, a magnetic disk, a floppy disk, etc.) or program storage device (such as an optical disk drive, magnetic disk drive, floppy disk drive, etc.). After reading this description, it will become apparent to a person skilled in the relevant art how to implement the system and method using computer systems and architectures.

Although specific embodiments of, and examples for, the present invention are described herein for illustrative purposes, various equivalent modifications are possible within the scope of the invention, as will be recognized by those skilled in the relevant art. The teachings provided herein of the present invention can be applied to other computing platforms, not necessarily the exemplary computing platform described above. For example, the teachings provided herein can be applied to UNIX machines as well.

In a telecommunications environment, aspects of the present invention generally can be applied to Internet metering data, marketing data on the success or failure of product offerings, telephone usage patterns, cash flow analyses, financial data, customer survey data on product reliability, customer survey data on product preference, etc. Moreover, aspects of

the present invention can be applied not only to a single performance metric of a computing platform, such as CPU utilization, but also to a plurality of performance metrics, such as disk drive usage percentage, Internet traffic, users logged on to the Internet, network communications packet traffic, and users logged onto a particular server, for example. The system and method may also be utilized to forecast these and other performance metrics for configuration management or performance management purposes.

These and other changes can be made to the invention in light of the above-detailed description. In general, in the following claims, the terms used should not be construed to limit the invention to the specific embodiments disclosed in the specification and claims, but should be construed to include all computer platforms that operate under the claims to provide a system and method for computing resource forecasting unitization.

From the foregoing it will be appreciated that, although specific embodiments of the invention have been described herein for purposes of illustration, various modifications may be made without deviating from the spirit and scope of the invention. Accordingly, the invention is not limited except as by the appended claims.

CLAIMS

1. In a computing platform having a plurality of resources, a method for forecasting at least one aspect of the plurality of resources, the method comprising the steps of:

collecting at intervals a metric from a computing platform resource; and

applying an autoregressive modeling tool to the collected metrics to produce a forecast of the metric of the plurality of resources.

2. The method according to claim 1, further comprising the step of statistically collapsing the collected metrics to produce a first time series.

3. The method according to claim 1, further comprising the step of outputting the forecast of the metric.

4. The method according to claim 1, further comprising the step of extracting the first time series from the database.

5. The method according to claim 1, further comprising the step of statistically collapsing the first time series to produce a second series.

6. The method according to claim 1, further comprising the step of ensuring that the first time series is statistically stationary.

7. A system to forecast performance of at least one computing platform resource, comprising:

* C L M S *

a computing platform resource having at least one performance metric; and

an autoregressive modeling tool for receiving a representation of the performance metric and providing a forecast of the computing platform resource.

8. The system of claim 7, wherein the autoregressive modeling tool is an autoregressive moving average modeling tool.

9. The system of claim 7, wherein the autoregressive modeling tool is an autoregressive integrated moving average modeling tool.

10. The system of claim 7, wherein the performance metric represents utilization of at least one computing platform resource.

11. The system of claim 7, wherein the performance metric represents one of redundancy or efficiency of at least one computing platform resource.

12. The system of claim 7, wherein the performance metric represents utilization and the computing platform resource comprises a central processing unit.

13. The system of claim 7, wherein the performance metric represents users logged on to the Internet.

14. The system of claim 7, wherein the performance metric represents Internet traffic.

* C L M S *

15. A system to forecast at least one aspect of a plurality of computing platform resources, comprising:

a resource manager;

a first statistical collapser coupled to the resource manager;

a time series analyzer coupled to the first statistical collapser; and

and autoregressive modeling tool coupled to the time series analyzer.

16. The system according to claim 15, further comprising a database coupled to the first statistical collapser.

17. The system according to claim 15, further comprising a data extractor coupled to the database.

18. The system according to claim 15 further comprising a second statistical collapser coupled to the data extractor.

19. The system according to claim 15, further comprising a time point converter coupled to the time series analyzer.

20. The system according to claim 15, wherein the first statistical collapser comprises a fifteen minute time series generator.

21. The system according to claim 15, wherein the second statistical collapser comprises a weekly time series generator.



22. The system according to claim 15, wherein the time series analyzer comprises a time series differencer.

23. The system according to claim 15, wherein the autoregressive modeling tool comprises an autoregressive moving average modeling tool.

24. The system according to claim 15, wherein the auotregressive modeling tool comprises an autoregressive integrated moving average modeling tool.

25. In a computing platform having a plurality of resources, a method for forecasting at least one aspect of the plurality of resources, the method comprising the steps of:

statistically collapsing a metric of a computing platform resource; and

applying an autoregressive modeling tool to a series of the statistically collapsed metrics to produce a forecast of the metric.

26. The method according to claim 25, further comprising the step of collecting at intervals the metric from the computing platform resource.

27. The method according to claim 25, further comprising the step of storing the series in a database.

28. The method according to claim 25, further comprising the step of extracting the series from the database.



29. The method according to claim 25, further comprising the step of statistically collapsing the series to produce a set of points.

30. The method according to claim 25, further comprising the step of ensuring that the set of points is statistically stationary.

31. In a computing platform having a plurality of resources, a method for producing a series of data values of the computing platform resources, the method comprising the steps of:

receiving a series of metrics representing at least one computing platform resource;

calculating a set of mean or median values based on the series of metrics;

determining a set of mean or median values for each calculated set of values;

collating the determined values to produce a series of data values representing the series of metrics; and

storing the series of metrics in a database.

32. The method according to claim 31, further comprising the step of collapsing the stored series of metrics to produce a first time series.

33. The method according to claim 31, further comprising the step of collapsing the first time series to produce a second time series.

34. The method according to claim 31, further comprising the step of applying an autoregressive model to the second time series.



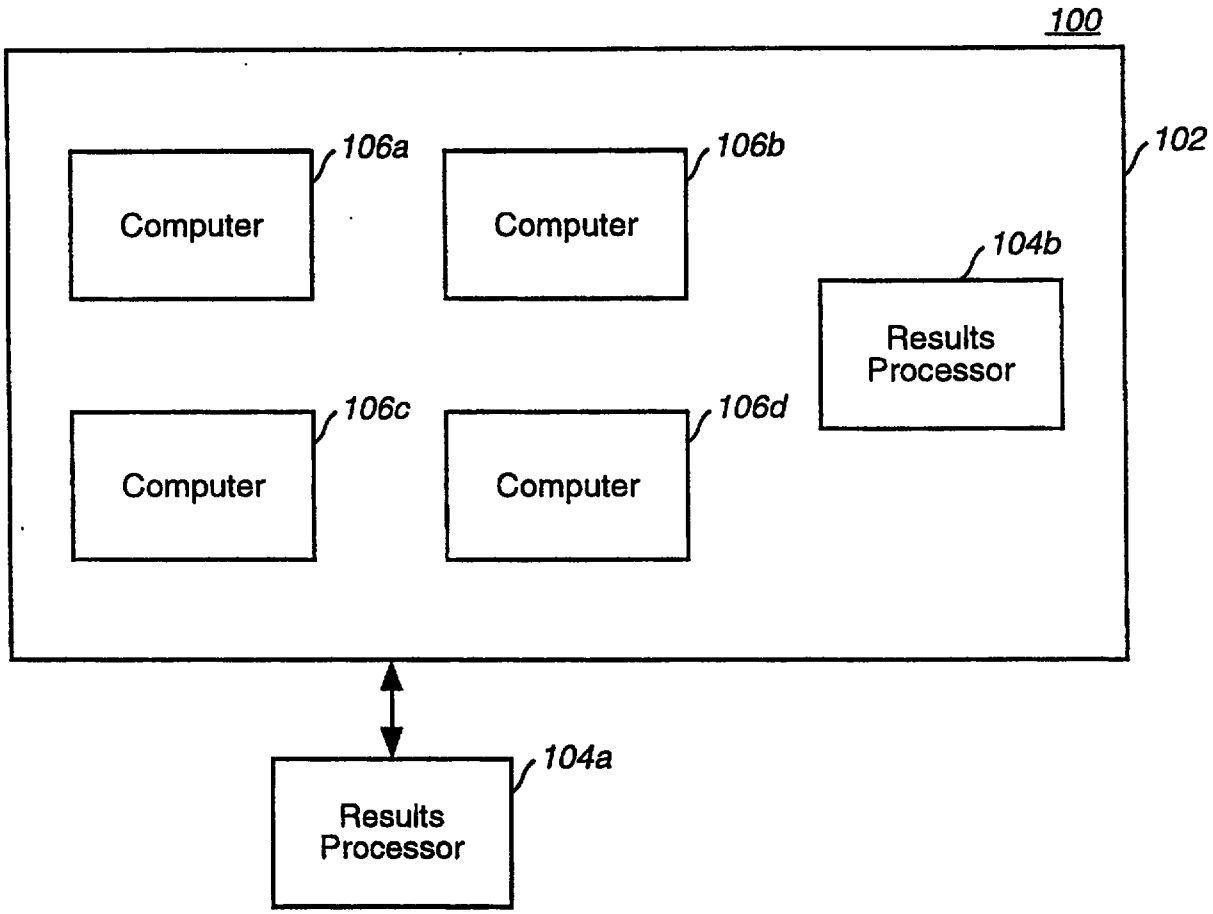

100
102
106a
Computer
106b
Computer
104b
Results Processor
106c
Computer
106d
Computer
104a
Results Processor

FIG. 1

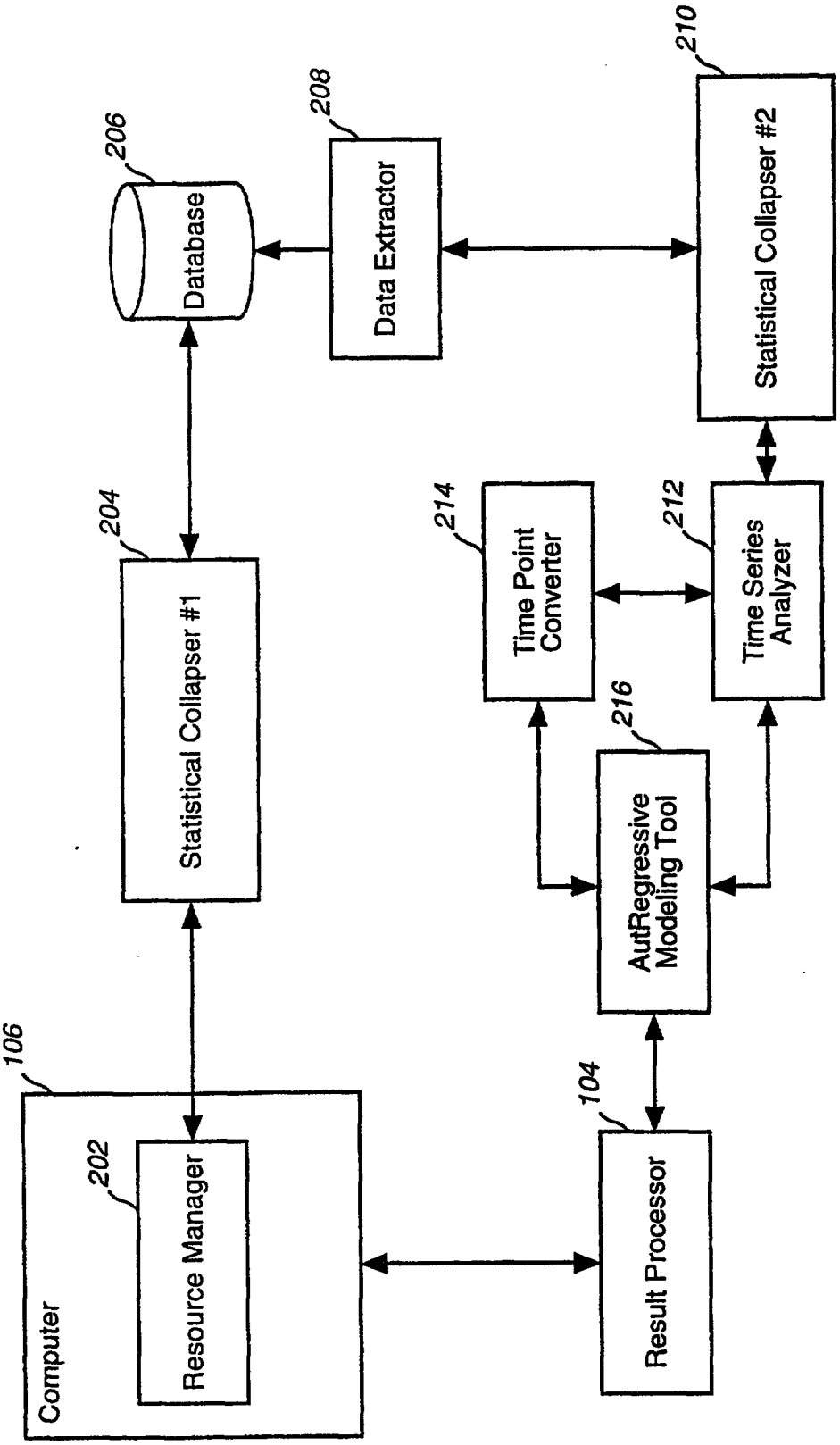

106
Computer
202
Resource Manager
204
Statistical Collapser #1
206
Database
208
Data Extractor
210
Statistical Collapser #2
104
Result Processor
216
AutRegressive Modeling Tool
214
Time Point Converter
212
Time Series Analyzer

FIG. 2

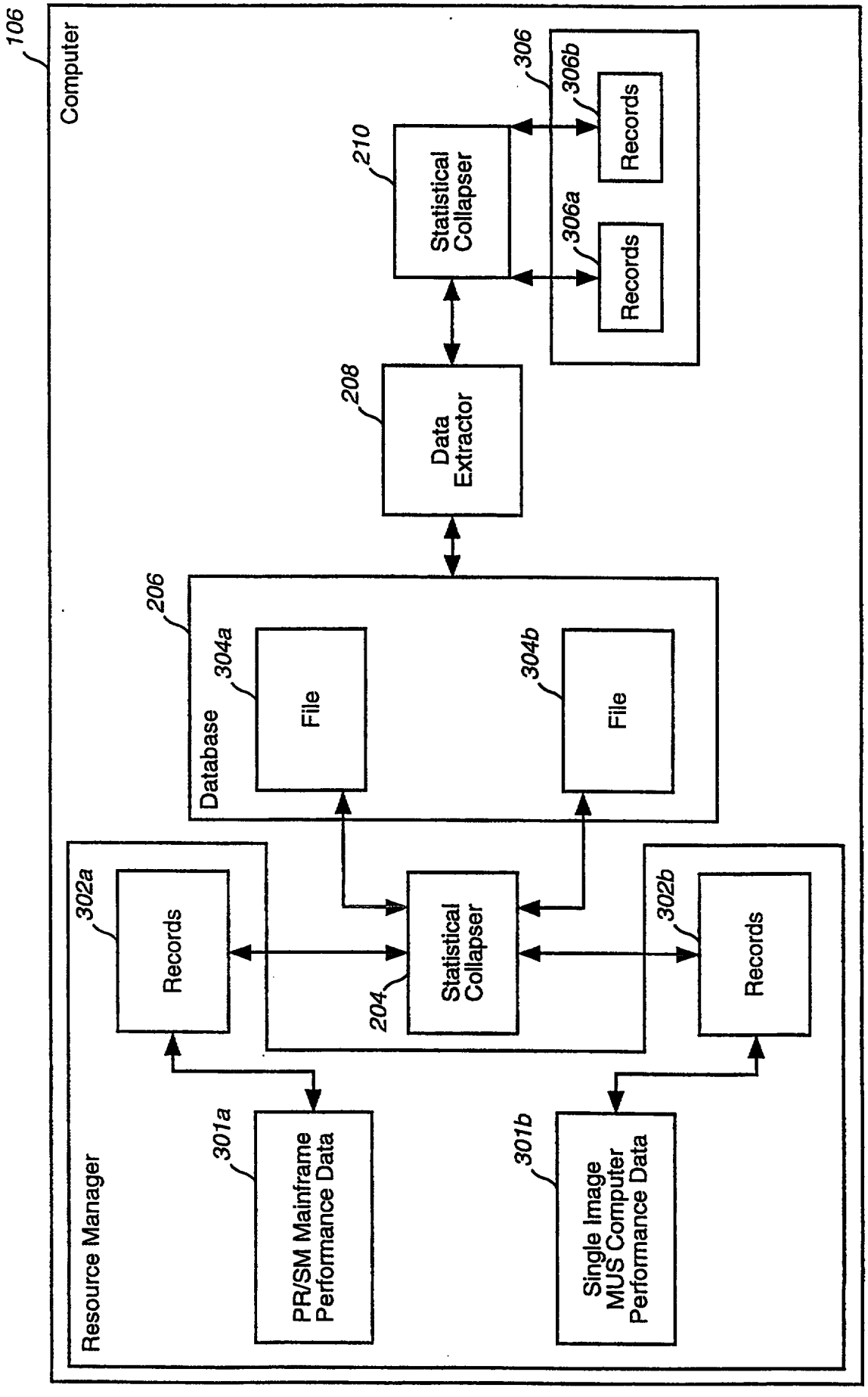

106
Computer
306
306b
Records
210
Statistical Collapser
306a
Records
208
Data Extractor
206
Database
304a
File
304b
File
Resource Manager
302a
Records
204
Statistical Collapser
302b
Records
301a
PR/SM Mainframe Performance Data
301b
Single Image MUS Computer Performance Data

FIG. 3

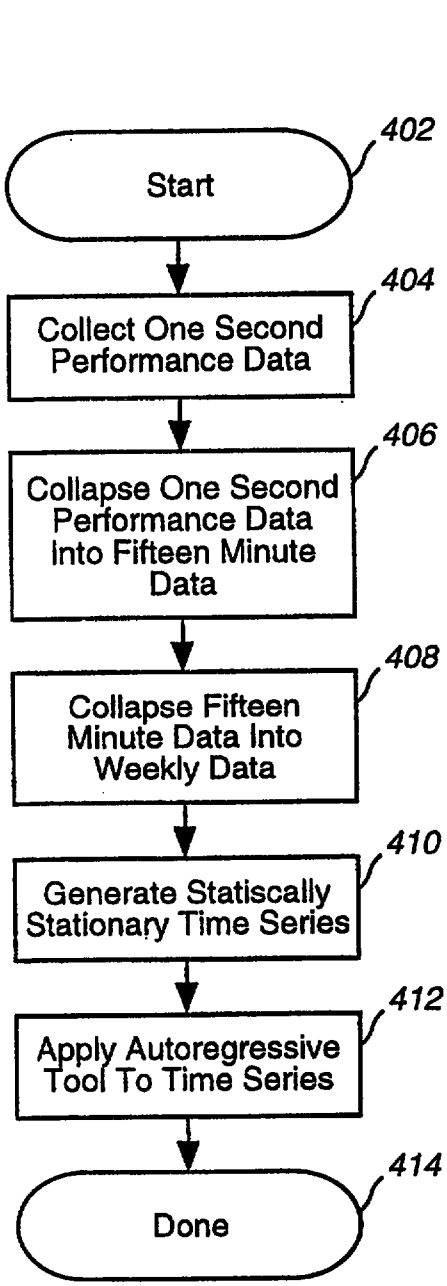

400
402
Start
404
Collect One Second Performance Data
406
Collapse One Second Performance Data Into Fifteen Minute Data
408
Collapse Fifteen Minute Data Into Weekly Data
410
Generate Statiscally Stationary Time Series
412
Apply Autoregressive Tool To Time Series
414
Done

FIG. 4

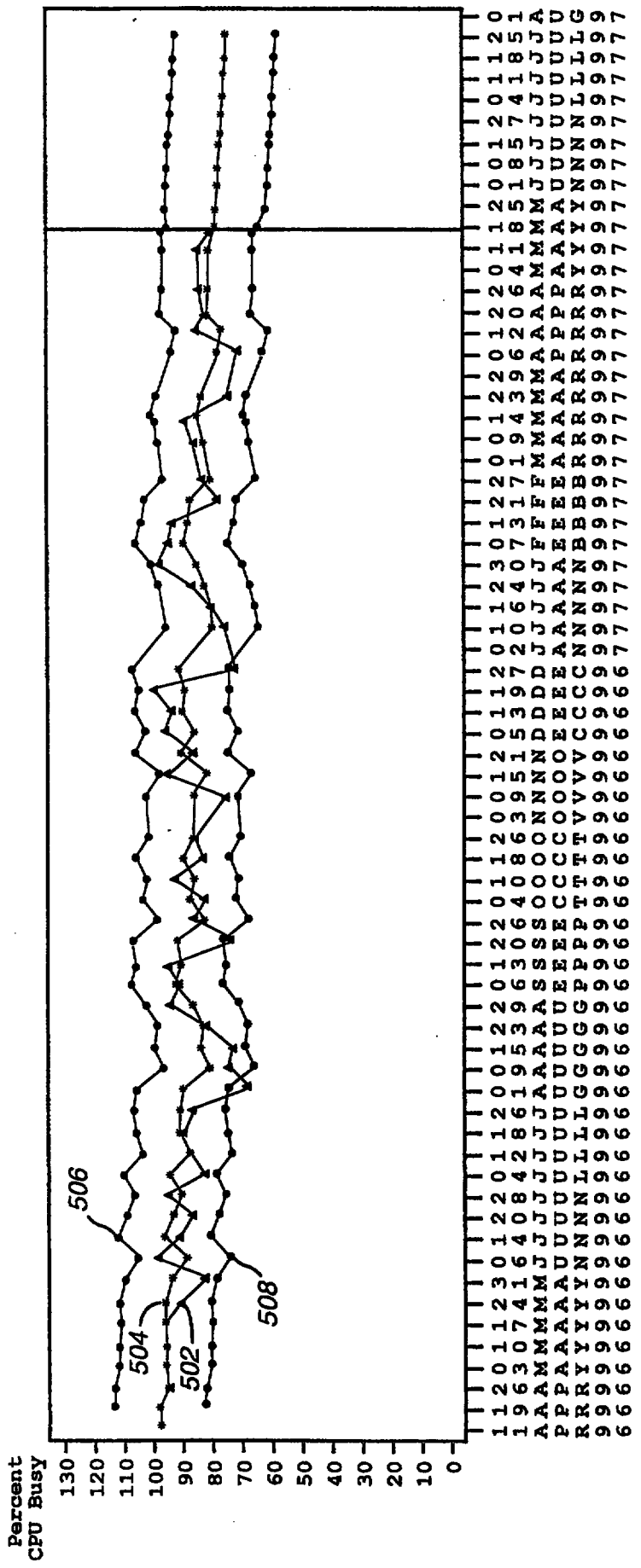

Percent CPU Busy
130
120
110
100
90
80
70
60
50
40
30
20
10
0
506
504
502
508
Data

FIG. 5

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(57) Abstract

A system and method for extracting and forecasting computing resource data such as workload consumption of mainframe computing resources using an autoregressive model. The system and method foresast mainframe central processing unit (CPU) consumption with ninety–five percent accuracy using historical perfomance data. The system and method also provide an upper ninety–five percent confidence level and a lower ninety–five percent confidence level. The system and method retrieve performance records from a computer platform in one second intervals, statistically collapses the one second performance data into fifteen minute performance data, statistically collapses the fifteen minute performance data into a one week performance data, and generates a time series equivalent to collecting performance data at one week intervals. The system and method ensure that the resulting time series is statistically stationary, and applies an autoregressive construct to the time series to generate forecast of future CPU utilization, as well as to generate reports and graphs comparing actual vs. forecast CPU utilization. Because the system and method rely on electronically generated empirical historical computer performance data as an input, they provide a turnkey solution to CPU consumption forecasting that can be implemented easily by any system network manager.