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(54) EVENT OVERFLOW HANDLING BY COALESCING AND UPDATING PREVIOUSLY-QUEUED EVENT NOTIFICATION

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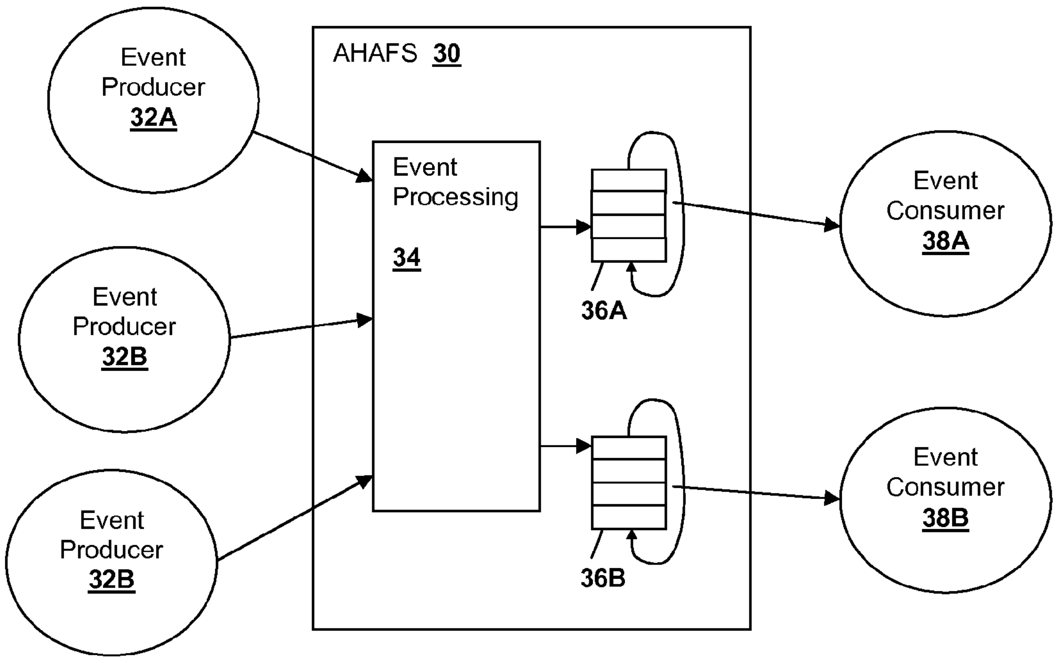
(57) **ABSTRACT**

An event notification system for distributed processing systems provides reduction of queue space and event processing bandwidth associated with duplicate events such as a particular event that is duplicated and results in multiple event notifications propagated for multiple consumers. When a duplicate event notification is received at an input to an event notification queue, rather than queuing the duplicate event notification, a sequence number of the event notification already in the queue is updated to indicate to the event consumer, exactly how many duplicate events have been received. The timestamp of the updated event notification may also be set to the timestamp of the most recently received duplicate event notification.



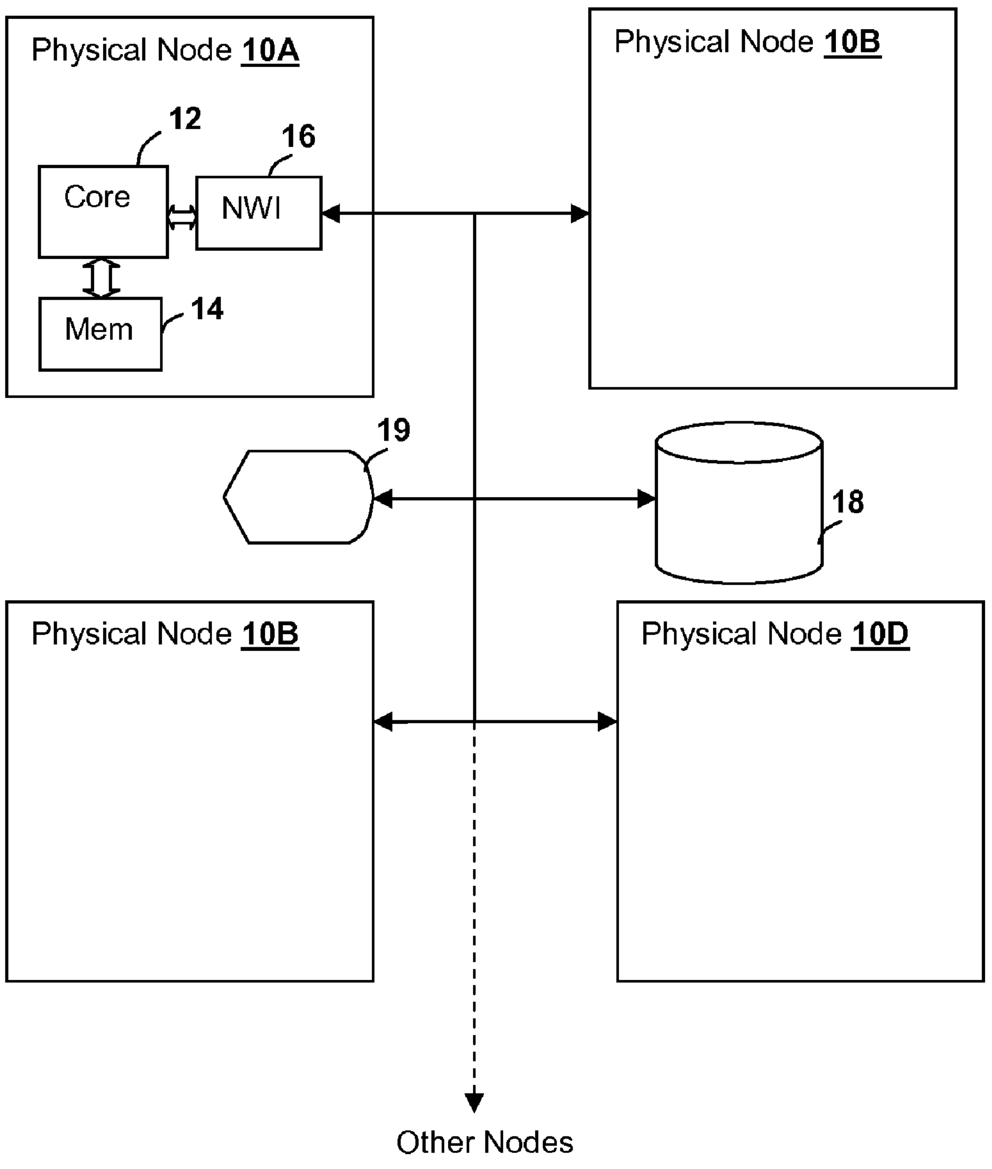

Physical Node 10A
12
Core
16
NWI
Mem
14
Physical Node 10B
19
18
Physical Node 10B
Physical Node 10D
Other Nodes

Fig. 1

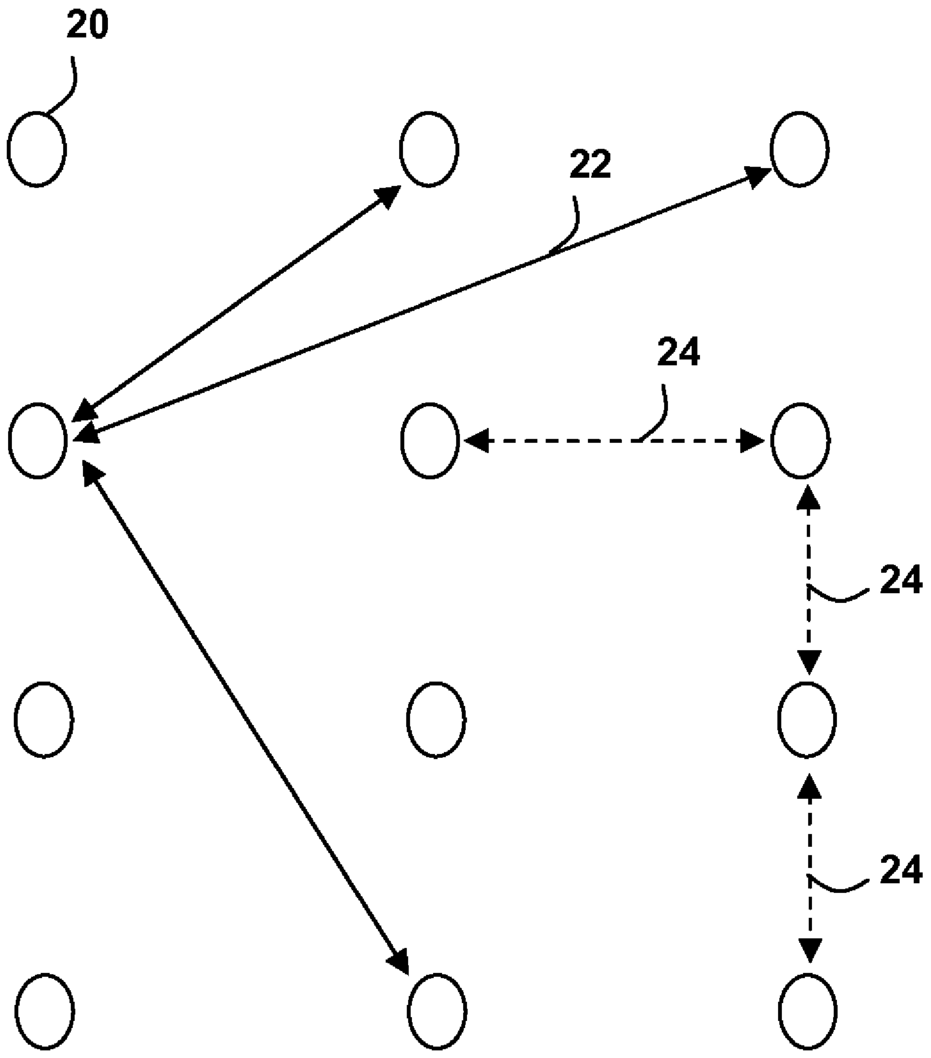


Fig. 2

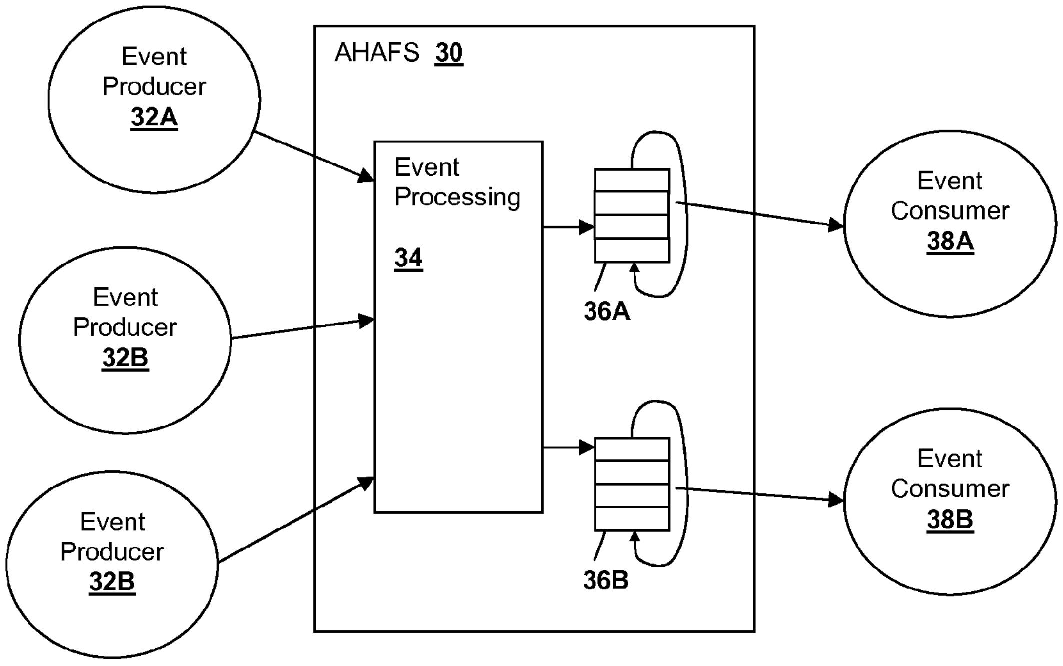

Event Producer 32A
Event Producer 32B
Event Producer 32B
AHAFS 30
Event Processing 34
36A
36B
Event Consumer 38A
Event Consumer 38B

Fig. 3

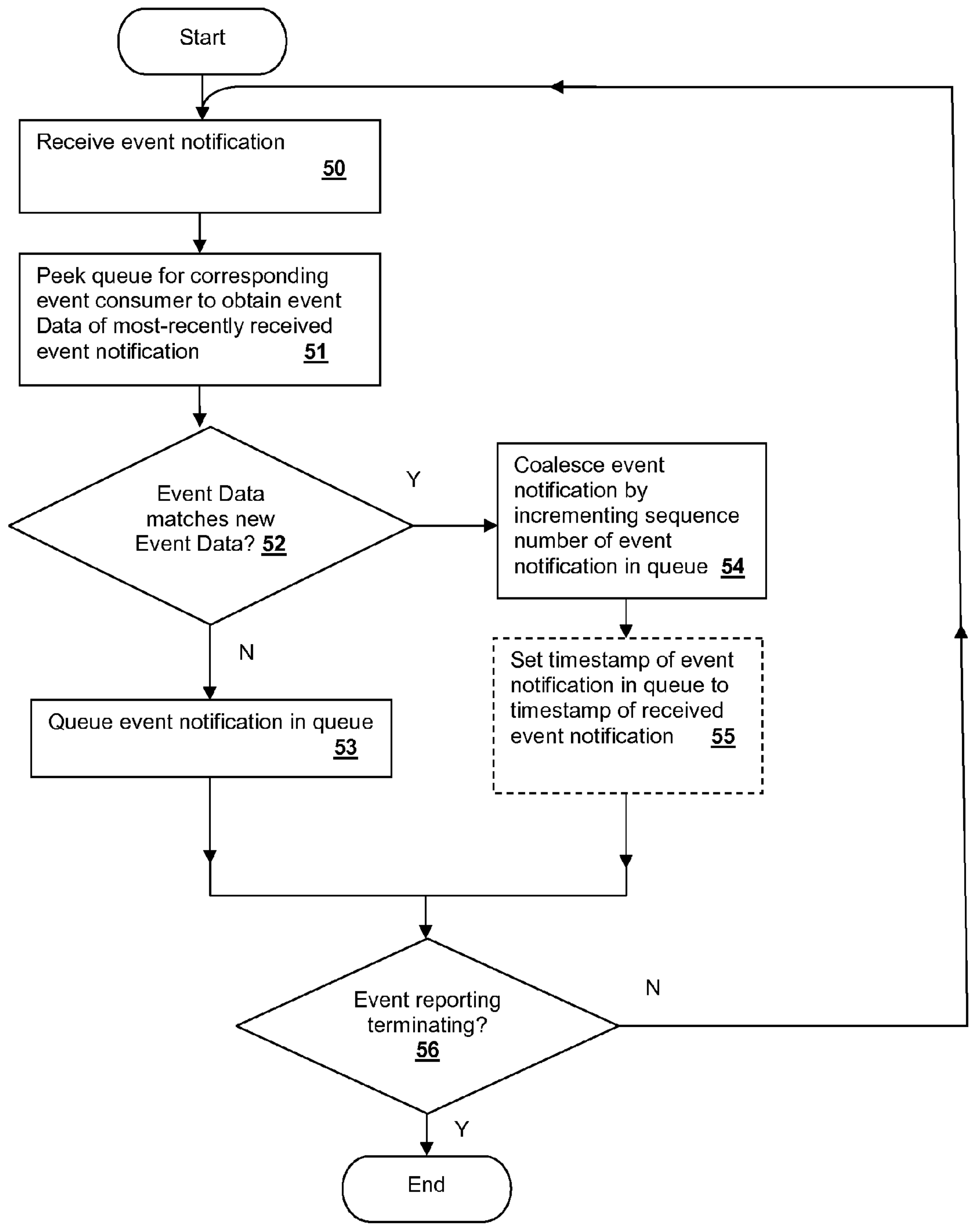

Start
Receive event notification 50
Peek queue for corresponding event consumer to obtain event Data of most-recently received event notification 51
Event Data matches new Event Data? 52
Y
Coalesce event notification by incrementing sequence number of event notification in queue 54
Set timestamp of event notification in queue to timestamp of received event notification 55
N
Queue event notification in queue 53
Event reporting terminating? 56
N
Y
End

Fig. 4

EVENT OVERFLOW HANDLING BY COALESCING AND UPDATING PREVIOUSLY-QUEUED EVENT NOTIFICATION

BACKGROUND

[0001] 1. Field of the Invention

[0002] The present invention is related to handling of event notification overflow or potential overflow conditions in computer systems, and more specifically to handling of duplicate events so that additional queue space is not required.

[0003] 2. Description of Related Art

[0004] In large-scale distributed computer systems, such as those using distributed software models to perform tasks, multiple nodes provide independent execution of sub-tasks. In order to keep such a system operational, and further, to provide indication of events occurring at one node that either require a reaction from another node or indicate to the other node that either an erroneous operating condition has occurred, or that a phase of processing is complete. In particular, event notification and event logging are operations used to indicate system health to system administrators or software applications, including operating systems components.

[0005] Health monitoring techniques employed in distributed processing systems perform an important function in that connections to other nodes must be reliable and all of the active nodes that have been assigned tasks need to perform those tasks in order to ensure that the totality of the processing requirements are met, and in a timely fashion. The health of a node-based distributed processing system is typically monitored by: 1) a heartbeat messaging system, which passes messages between the nodes and a central monitoring component; and 2) an event notification system that signals interested nodes when events occur on other nodes. Event notification systems in node-based distributed processing systems typically require an interested application (a consumer) to register to receive event notifications either with a centralized event manager, or with the processes or objects that generate the events (an event producer).

[0006] Events in such a system may be reported multiple times. For example, an event may be reported for each interested event consumer. With the large number of events that may be generated, in particular where the event itself is triggered multiple times due to a resource change or a hardware or media failure, a large number of duplicate events may be buffered at a node, causing event queue overflow and/or consuming processing bandwidth that could be used to handle other events. While the duplicate events could simply be removed from the queue, information about how many events have occurred and the timing of the events may be lost.

BRIEF SUMMARY

[0007] The invention provides an event notification system and method that is embodied in a computer-performed method, a computer program product and computer systems. The method, which is implemented by the computer program product and computer system, provides queuing of events to event consumers, while coalescing duplicate events.

[0008] When a duplicate event notification is detected at the input to a queue that stores event notifications for delivery to an event consumer, rather than queuing the event notification, a previously-received event notification is updated by incrementing the sequence number of the previously-received event notification. Therefore, when the event consumer receives the event notification, the event consumer can determine exactly how many events the coalesced event notification represents. The timestamp of the event notification may also be updated to match the timestamp of the most recently-received duplicate event notification.

[0009] The foregoing and other objectives, features, and advantages of the invention will be apparent from the following, more particular, description of the preferred embodiments of the invention, as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

[0010] The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, however, as well as a preferred mode of use, further objectives, and advantages thereof, will best be understood by reference to the following detailed description of the invention when read in conjunction with the accompanying Figures, wherein like reference numerals indicate like components, and:

[0011] FIG. **1** is a block diagram of a distributed computer system in which techniques according to an embodiment of the present invention are practiced.

[0012] FIG. **2** is a pictorial diagram depicting communication between nodes of a computer system in accordance with an embodiment of the present invention.

[0013] FIG. **3** is a pictorial diagram depicting information flow in a computer system in accordance with an embodiment of the present invention.

[0014] FIG. **4** is a flowchart of a method in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

[0015] The present invention encompasses techniques for event notification in clusters of nodes within distributed computing systems. In particular, embodiments of the invention can be used to reduce event processing bandwidth and storage requirements by coalescing duplicate events that are being queued for delivery to event consumers. Information about how many duplicate events is preserved by incrementing a sequence number within the event notification when a duplicate event is combined with a previously queued event notification. The timestamp of the event notification can be updated with the timestamp of the most recently received duplicate event.

[0016] Referring now to FIG. **1**, a distributed computer system in accordance with an embodiment of the present invention is shown. A first physical processing node **10**A includes a processor core **12** coupled to a memory **14** that stores program instructions for execution by processor **12**. The program instructions include program instructions forming computer program products in accordance with embodiments of the invention that provide event notification between either physical processing nodes **10**A-**10**D, virtual processing nodes partitioned within the depicted computer system as will be described in further detail below, or both. Processing node **10**A also includes a network interface (NWI) **16** that couples processing node **10**A to a wired, wireless or hybrid network, which may be a standardized network such as Ethernet, or a proprietary network or interconnect bus. Other processing nodes **10**B-**10**D are of identical construction in the exemplary embodiment, but embodiments of the invention may be practiced in asymmetric distributed systems having nodes with differing features. Although only four compute nodes **10**A-**10**D are illustrated, a distributed computer system in accordance with an embodiment of the present invention will generally include a large number of compute nodes connected via one or more networks. The distributed computer system of FIG. **1** also includes other resources such as I/O devices **19**, including graphical display devices, printers, scanners, keyboards, mice, which may be coupled to the network or one of nodes **10**A-**10**D via workstation computers that provide a user interface to administrative personnel and other users. Nodes **10**A-**10**D are also coupled to storage devices **18**, for storing and retrieving data and program instructions, such as storing computer program products in accordance with an embodiment of the invention.

[0017] Referring now to FIG. **2**, communication between multiple nodes **20** of the distributed computer system of FIG. **1** is shown. As mentioned above, nodes **20** may correspond exactly on a one-to-one basis with processing nodes **10**A-**10**D (and other nodes) of FIG. **1**, or nodes **20** may be partitioned in a different manner as virtual processing nodes. For example, a single node **20** may have exclusive use of multiple processing nodes, e.g. nodes **10**A-**10**B, and result in a system having a greater number of virtual nodes than processing nodes, or alternatively, multiple nodes **20** may be implemented on a single processing node, e.g., node **10**A. In the present invention, each of nodes **20** represents at least one operating system image and one or more applications executing within the operating system image. In general, the entire system as depicted may execute a single application, but sub-tasks within the application are apportioned to the various nodes **20**, which may be identical sub-tasks or different sub-tasks. The present invention concerns event notification within the computer system of FIG. **1**, in which events are communicated between nodes **20** via event notification messages. Other messages are also passed between nodes **20**, including data and program code transmissions, and messages as needed to support features of embodiments of the present invention, such as indications to remote nodes that event notifications of a particular event type are of interest to another node. A separate physical network may be provided for administrative tasks such as event notification and heartbeat messaging, or the same physical networks may be used. Nodes are generally arranged in a cluster, which is a group of virtual or physical processing nodes organized to perform a particular task or group of tasks, e.g., for a particular customer. As illustrated, communication between nodes in a cluster may be accomplished by direct node to node communications **22** or by next-neighbor communications **24** in which nodes **20** pass along messages to other nodes **20**. Another alternative is to use a central facility for inter-node communication. However, since the present invention provides a high availability event notification system having low latency, it is generally preferable not to use a central clearinghouse for events and other messages.

[0018] While event notification in accordance with embodiments of the present invention may be implemented using a variety of event notification mechanisms, such as direct object-to-object interfaces, using operating system-maintained signaling object such as semaphores, in the depicted embodiment, the event notification is provided by a special file system that implements an event manager. Event consumers, i.e., the applications or objects interested in receiving event notifications, register to receive event notifications by calling file operation functions/methods on an interface to the file system. Event producers notify the file system of events via a separate application programming interface (API) provided by the event manager. The event manager then provides the event notifications to the event consumers interested in the particular events represented by the event notifications. In the depicted embodiment, the file system is a kernel extension, which facilitates availability and uniformity of the event manager at each node in the system. Further details of a file-system based event manager are provided in U.S. Patent Application Publication U.S. 200901991051, which is incorporated herein by reference. The event notification system the "Autonomic Health Advisor File System" (AHAFS) disclosed in the above-incorporated U.S. patent Application does not provide direct event notification between the nodes, so a separate layer is used for inter-node event communication. The generic methods open( ) and write( ) described below are understood to include specific file operations fopen( ) and fwrite( ) as alternatives, or other operations provided in a file system interface that can be used to provide the same type of information flow.

[0019] Referring now to FIG. **3**, information flow within an event notification system according to an embodiment of the invention is shown. Event producers **32**A-**32**C generate event notifications that are provided to an event processing block **34** within an AHAFS software component **30**, which is generally distributed among nodes **20**. Instances of an AHAFS interface on each node **20** receive event notifications from event producers **32**A-**32**C and either queue them for local consumption or transmit them for remote consumption. AHAFS software component **30** also receives remote event notifications from remote instances of AHAFS interfaces. Both local events and remote event notifications are queued by AHAFS software component **30** in per-consumer queues **36**A and **36**B, which are implemented as circular buffers in the depicted embodiment, but may alternatively be implemented using other type of storage organization. Event consumers **38**A-**38**B process events de-queued from their corresponding queues **36**A and **36**B, and perform any responsive actions.

[0020] The present invention provides reduction in processing overhead and the chance of overflow of queues **36**A and **36**B, by detecting that a duplicate event notification is about to be inserted in one of queues **36**A and **36**B, and altering the event notification to indicate to the corresponding event consumer **38**A-**38**B, the number of event notifications represented by the modified event notification, and the timestamp of the latest such event notification received.

TABLE I

Event Notification Tag	
Event type (per consumer)	e
Event sequence number	1
Timestamp	
Event Data . . .	
End Tag	

Table I above illustrates an event notification received for a first event e, which has an event sequence number of 1. If additional identical event notifications having the same data are received, the AHAFS according to an embodiment of the present invention will increment the event sequence number for each duplicate event that is then received and discarded.

When the corresponding event consumer processes the event notification, the consumer can determine the number of event notifications received by the value of the event sequence number. Since the field (event sequence number) used to store the indication that more than one event has been received is a field already within the event notification, the event consumers do not have to handle a new/different format that includes additional fields to indicate a duplicate event. Therefore, the same parsing format can be used to interpret the event notification, since the coalesced event notification has the same format as an individual event notification.

[0021] The event consumer can also determine the most recent occurrence of the event by noting the timestamp, which has been replaced with the timestamps of the incoming event notifications as they are received and discarded. In the particular embodiment depicted herein, if a different event notification is received between duplicate event notifications, then the more recent event notifications are not discarded, so the event consumer can rely that no other events have transpired between the event notifications that have been coalesced. The updating of timestamps can be user settable in accordance with an embodiment of the present invention to update with the latest timestamp, or retain the timestamp of the first occurrence of the event, which may be selected on a per-customer basis. As another alternative embodiment, event consumers, when registering to receive notifications for a particular event, may be provided the option of specifying a flag, e.g., TIMESTAMP=FIRST or TIMESTAMP=LAST, which in the depicted embodiment are written to the file that represents the event. The flag indicates, for each event consumer and on a per event-type basis, whether the timestamp field is updated with each received event notification that is coalesced, or whether the original timestamp is preserved.

[0022] Referring now to FIG. **4**, a method in accordance with an embodiment of the invention is shown in a flowchart. When an event notification is received for an event consumer (step **50**), the corresponding queue tail is peeked (step **51**) to determine if the event data matches the event data of the event notification received in step **50** (decision **52**). If the event data matches (decision **52**), the event notifications are coalesced by incrementing the sequence number of the event stored in the queue tail (step **54**) and the timestamp of the event received in step **50** is optionally used to replace the timestamp in the queue tail event notification (step **55**). Whether or not the timestamp is replaced can be determined from a user-settable flag that indicates whether timestamp updating should be employed. If the event data does not match (decision **52**), then the received event notification is enqueued in the queue (step **53**). Until event reporting is terminated (decision **56**) the process of steps **50**-**56** are repeated as event notifications arrive at each queue.

[0023] As noted above, the present invention may be embodied as a system, method, and/or a computer program product. A computer program product may be embodied in firmware, an image in system memory or another memory/cache, stored on a fixed or re-writable media such as an optical disc having computer-readable code stored thereon. Any combination of one or more computer readable medium (s) may be used to store the program instructions in accordance with an embodiment of the invention. The computer readable medium may be a computer readable signal medium or a computer readable storage medium. A computer readable storage medium may be, for example, but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, or device, or any suitable combination of the foregoing. More specific examples (a non-exhaustive list) of the computer readable storage medium would include the following: an electrical connection having one or more wires, a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), an optical fiber, a portable compact disc read-only memory (CD-ROM), an optical storage device, a magnetic storage device, or any suitable combination of the foregoing.

[0024] In the context of the present application, a computer readable storage medium may be any tangible medium that can contain, or store a program for use by or in connection with an instruction execution system, apparatus, or device. A computer readable signal medium may include a propagated data signal with computer readable program code embodied therein, for example, in baseband or as part of a carrier wave. Such a propagated signal may take any of a variety of forms, including, but not limited to, electro-magnetic, optical, or any suitable combination thereof. A computer readable signal medium may be any computer readable medium that is not a computer readable storage medium and that can communicate, propagate, or transport a program for use by or in connection with an instruction execution system, apparatus, or device. Program code embodied on a computer readable medium may be transmitted using any appropriate medium, including but not limited to wireless, wireline, optical fiber cable, RF, or any suitable combination of the foregoing.

[0025] Computer program code for carrying out operations for aspects of the present invention may be written in any combination of one or more programming languages, including an object oriented programming language such as Java, Smalltalk, C++ or the like and conventional procedural programming languages, such as the "C" programming language or similar programming languages. Further, while the illustrative embodiment is directed to an AIX (AIX is a trademark of IBM) or other type of UNIX operating system (UNIX is a trademark of The Open Group), in which the event notification is provided by a mountable file system provided as a kernel extension, it is understood that the techniques of the present invention can be applied in event monitoring systems executing under any operating system and can be implemented using proprietary or standardized signaling interfaces as an alternative to the file system interface provided in the depicted embodiments.

[0026] While the invention has been particularly shown and described with reference to the preferred embodiments thereof, it will be understood by those skilled in the art that the foregoing and other changes in form and details may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. A method for event notification within a computer system processing cluster comprising a plurality of physical or virtual processing modes, the method comprising:

receiving event notifications corresponding to events occurring on one or more of the processing nodes;

queuing the received event notifications in one or more queues for delivery to event consumers;

coalescing duplicate event notifications in a single resulting event notification, wherein the event notifications contain a event sequence number, wherein the coalescing further increments the event sequence number in the resulting event notification to indicate to a corresponding one of the event consumers the total number of original and duplicate events that have been received; and

at an event consumer, determining whether the event notifications have been duplicated one or more times by reading the event sequence number of the event notifications.

2. The method of claim **1**, wherein the queuing the event notifications queues the event notifications in multiple queues corresponding to event consumers.

3. The method of claim **1**, wherein the coalescing only coalesces sequential duplicate events.

4. The method of claim **3**, wherein the coalescing comprises:

responsive to the receiving having received an event notification;

peeking in a corresponding queue to determine whether a most recently queued event notification is a duplicate of the received event notification;

responsive to the peeking determining that the most recently queued event notification is not a duplicate of the received event notification, queuing the event notification in the corresponding queue without altering the sequence number of the event notification; and

responsive to the peeking determining that the most recently queued event notification is a duplicate of the received event notification, incrementing the sequence number of the most recently queued event notification without queuing the received event notification in the queue.

5. The method of claim **4**, further responsive to the peeking determining that the most recently queued event notification is a duplicate of the received event notification, updating a timestamp of the most recently queued event notification.

6. The method of claim **1**, wherein the coalescing further sets a timestamp of the single resulting event notification to match the timestamp of the most recent of the duplicate event notifications.

7. The method of claim **6**, wherein the setting a timestamp is performed selectively in response to an indication that event notification timestamps should be updated.

8. The method of claim **1**, wherein the event notifications are received as callbacks to an application programming interface provided by the file system that implements at least a portion of the event notification method, and wherein the queuing is performed in response to receiving the callbacks.

9. A computer system comprising a processing cluster including a plurality of physical or virtual processing modes, the computer system comprising at least one processor for executing program instructions and at least one memory coupled to the processor for executing the program instructions, wherein the program instructions are program instructions for providing event notification within the computer system, the program instructions comprising program instructions for:

receiving event notifications corresponding to events occurring on one or more of the processing nodes;

queuing the received event notifications in one or more queues for delivery to event consumers;

coalescing duplicate event notifications in a single resulting event notification, wherein the event notifications contain a event sequence number, wherein the coalescing further increments the event sequence number in the resulting event notification to indicate to a corresponding one of the event consumers the total number of original and duplicate events that have been received; and

at an event consumer, determining whether the event notifications have been duplicated one or more times by reading the event sequence number of the event notifications.

10. The computer system of claim **9**, wherein the program instructions for queuing the event notifications queue the event notifications in multiple queues corresponding to event consumers.

11. The computer system of claim **9**, wherein the program instructions for coalescing only coalesce sequential duplicate events.

12. The computer system of claim **11**, wherein the program instructions for coalescing comprise program instructions for:

responsive to the receiving having received an event notification;

peeking in a corresponding queue to determine whether a most recently queued event notification is a duplicate of the received event notification;

responsive to the peeking determining that the most recently queued event notification is not a duplicate of the received event notification, queuing the event notification in the corresponding queue without altering the sequence number of the event notification; and

responsive to the peeking determining that the most recently queued event notification is a duplicate of the received event notification, incrementing the sequence number of the most recently queued event notification without queuing the received event notification in the queue.

13. The computer system of claim **12**, further comprising program instructions for responsive to the peeking determining that the most recently queued event notification is a duplicate of the received event notification, updating a timestamp of the most recently queued event notification.

14. The computer system of claim **9**, wherein the program instructions for coalescing further set a timestamp of the single resulting event notification to match the timestamp of the most recent of the duplicate event notifications.

15. The computer system of claim **9**, wherein the program instructions for setting a timestamp are selectively executed in response to an indication that event notification timestamps should be updated.

16. The computer system of claim **9**, wherein the event notifications are received as callbacks to an application programming interface provided by the file system that implements at least a portion of the event notification method, and wherein the program instructions for queuing are executed in response to receiving the callbacks.

17. A computer program product comprising a computer-readable storage media storing program instructions for execution within a computer system, the computer system comprising a processing cluster including a plurality of physical or virtual processing modes, wherein the program instructions are program instructions for providing event notification within the computer system, the program instructions comprising program instructions for:

receiving event notifications corresponding to events occurring on one or more of the processing nodes;

queuing the received event notifications in one or more queues for delivery to event consumers;

coalescing duplicate event notifications in a single resulting event notification, wherein the event notifications contain a event sequence number, wherein the coalescing further increments the event sequence number in the resulting event notification to indicate to a corresponding one of the event consumers the total number of original and duplicate events that have been received; and

at an event consumer, determining whether the event notifications have been duplicated one or more times by reading the event sequence number of the event notifications.

18. The computer program product of claim **17**, wherein the program instructions for queuing the event notifications queue the event notifications in multiple queues corresponding to event consumers.

19. The computer program product of claim **17**, wherein the program instructions for coalescing only coalesce sequential duplicate events.

20. The computer program product of claim **19**, wherein the program instructions for coalescing comprise program instructions for:

responsive to the receiving having received an event notification;

peeking in a corresponding queue to determine whether a most recently queued event notification is a duplicate of the received event notification;

responsive to the peeking determining that the most recently queued event notification is not a duplicate of the received event notification, queuing the event notification in the corresponding queue without altering the sequence number of the event notification; and

responsive to the peeking determining that the most recently queued event notification is a duplicate of the received event notification, incrementing the sequence number of the most recently queued event notification without queuing the received event notification in the queue.

21. The computer program product of claim **20**, further comprising program instructions for responsive to the peeking determining that the most recently queued event notification is a duplicate of the received event notification, updating a timestamp of the most recently queued event notification.

22. The computer program product of claim **17**, wherein the program instructions for setting a timestamp are selectively executed in response to an indication that event notification timestamps should be updated.

23. The computer program product of claim **17**, wherein the event notifications are received as callbacks to an application programming interface provided by the file system that implements at least a portion of the event notification method, and wherein the program instructions for queuing are executed in response to receiving the callbacks.

24. A computer system comprising a processing cluster including a plurality of physical or virtual processing modes, the computer system comprising at least one processor and at least one memory coupled to the processor, and wherein the computer system further comprises a file system device implementing an event notification system that includes one or more program modules having program instructions for:

receiving event notifications corresponding to events occurring on one or more of the processing nodes as callbacks to an application programming interface of the file system device;

queuing the received event notifications in one or more queues for delivery to event consumers;

coalescing duplicate event notifications in a single resulting event notification, wherein the event notifications contain a event sequence number, wherein the coalescing further increments the event sequence number in the resulting event notification to indicate to a corresponding one of the event consumers the total number of original and duplicate events that have been received; and

at an event consumer, determining whether the event notifications have been duplicated one or more times by reading the event sequence number of the event notifications.

25. A computer program product comprising a computer-readable storage media storing program instructions for execution within a computer system, the computer system comprising a processing cluster including a plurality of physical or virtual processing modes, wherein the program instructions comprise program instructions forming a file system device implementing an event notification system that includes one or more program modules having program instructions for:

receiving event notifications corresponding to events occurring on one or more of the processing nodes as callbacks to an application programming interface of the file system device;

queuing the received event notifications in one or more queues for delivery to event consumers;

coalescing duplicate event notifications in a single resulting event notification, wherein the event notifications contain a event sequence number, wherein the coalescing further increments the event sequence number in the resulting event notification to indicate to a corresponding one of the event consumers the total number of original and duplicate events that have been received; and

at an event consumer, determining whether the event notifications have been duplicated one or more times by reading the event sequence number of the event notifications.

* * * * *