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(54) SYSTEM AND METHOD FOR DIVIDING COMPUTATIONS

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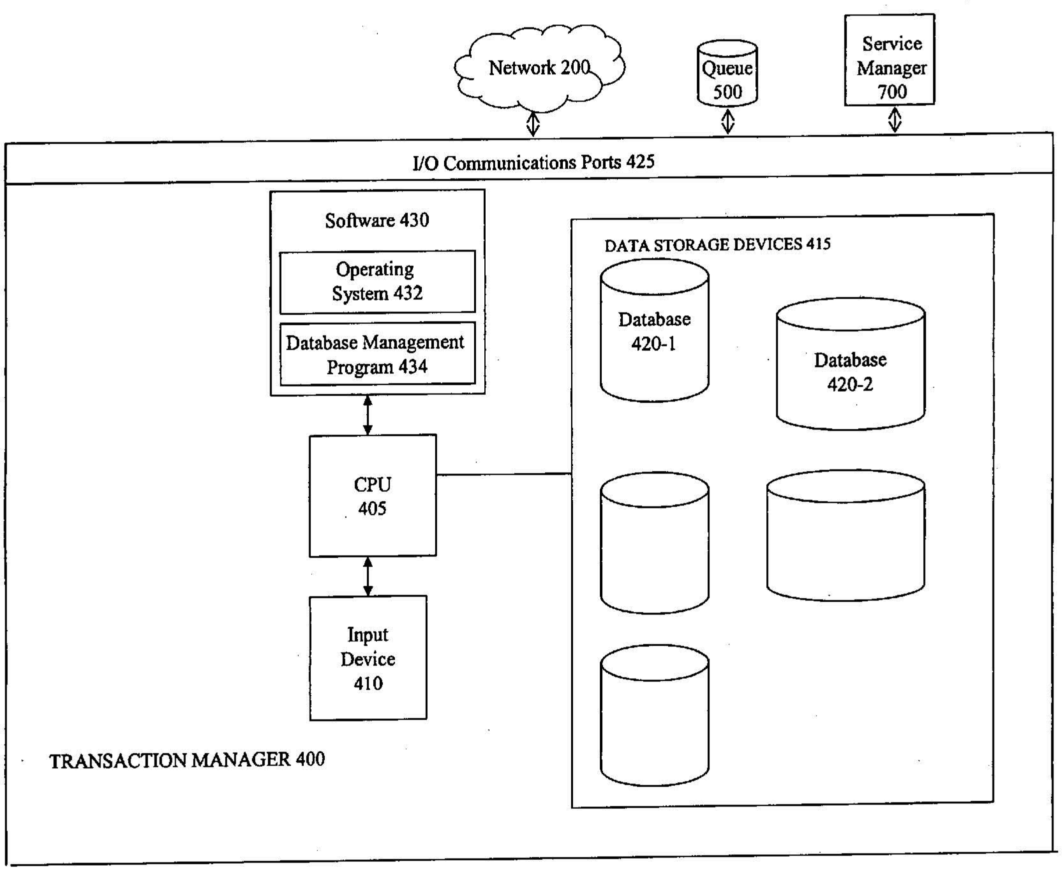
(57) ABSTRACT

In certain aspects, the invention features a system and method for receiving a parent job configured to produce one or more descendant jobs, and scheduling computation of the parent job on a node computing device that is one of a plurality of node computing devices of a distributed computing system. In such an aspect, the distributed computing system further includes a scheduler server configured to selectively reschedule computation of a job other than a parent job from any one of the plurality of node computing devices to another of the node computing devices. Such an aspect further includes preventing rescheduling of the parent job unless each of the descendant jobs is completed or terminated. In other aspects, the invention features a system and method for receiving, for computation by a node computing device, a parent job configured to produce a descendant job, wherein the node computing device is one of a plurality of node computing devices of a distributed computing system that also includes a scheduler server. In such aspects, the distributed computing system creates the descendant job, and the parent and descendant jobs are scheduled for computation on different node computing devices.



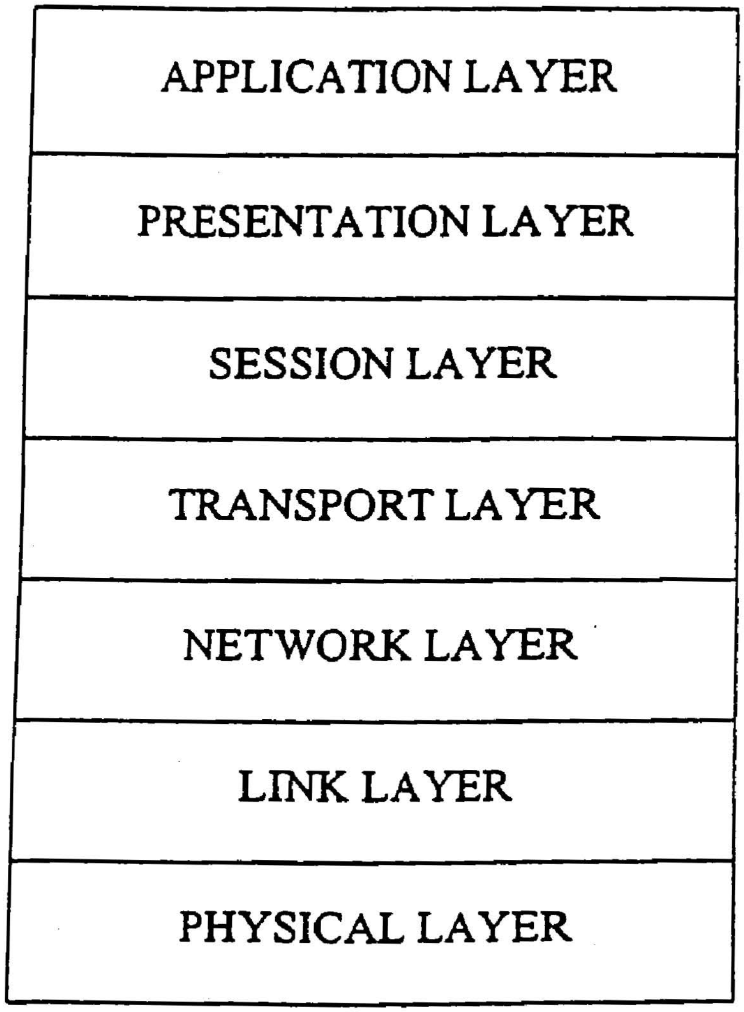

APPLICATION LAYER
PRESENTATION LAYER
SESSION LAYER
TRANSPORT LAYER
NETWORK LAYER
LINK LAYER
PHYSICAL LAYER

FIG. 1

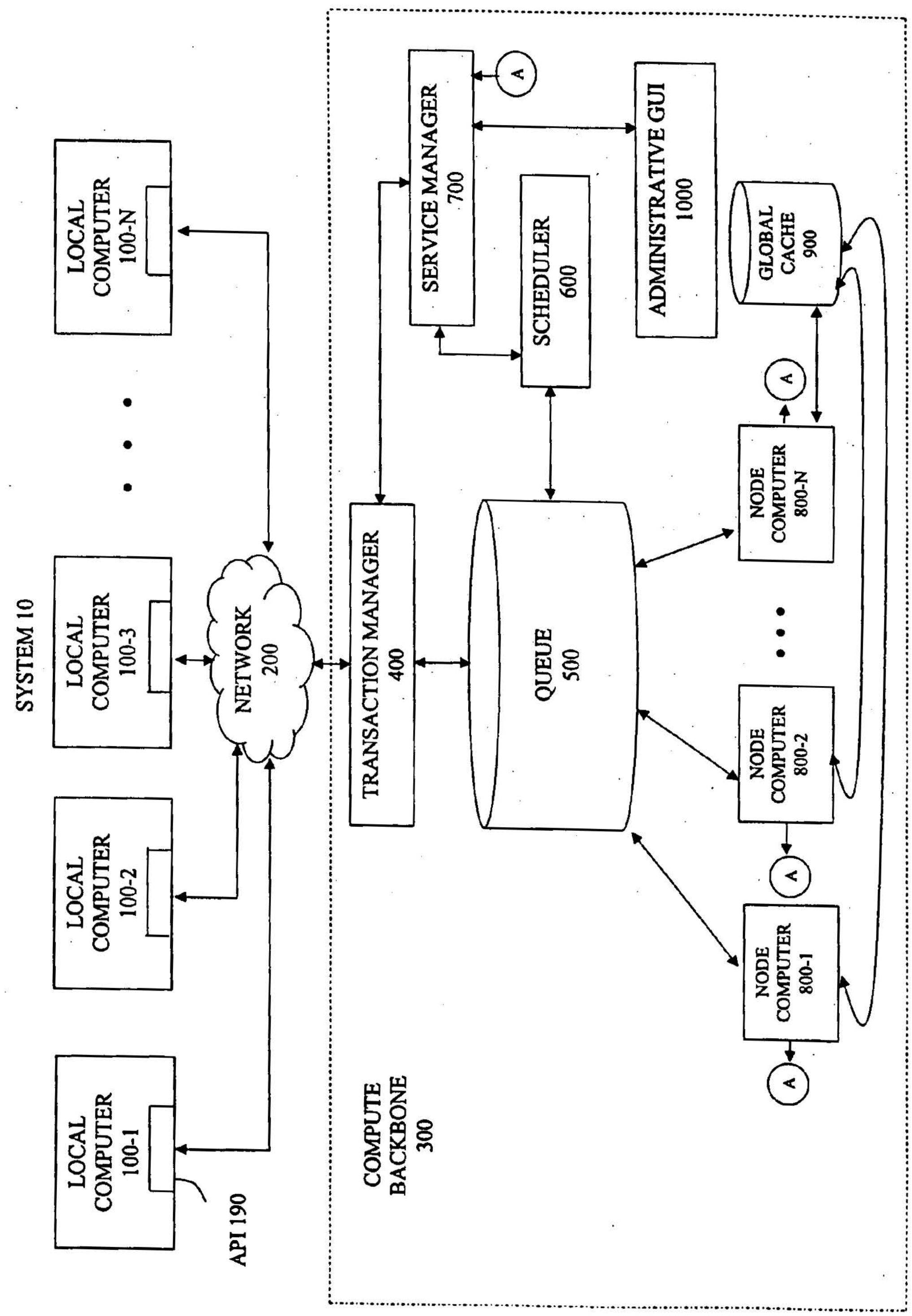

SYSTEM 10
LOCAL COMPUTER 100-1
API 190
LOCAL COMPUTER 100-2
LOCAL COMPUTER 100-3
LOCAL COMPUTER 100-N
NETWORK 200
COMPUTE BACKBONE 300
TRANSACTION MANAGER 400
QUEUE 500
SCHEDULER 600
SERVICE MANAGER 700
ADMINISTRATIVE GUI 1000
GLOBAL CACHE 900
NODE COMPUTER 800-1
NODE COMPUTER 800-2
NODE COMPUTER 800-N
A

FIG. 2

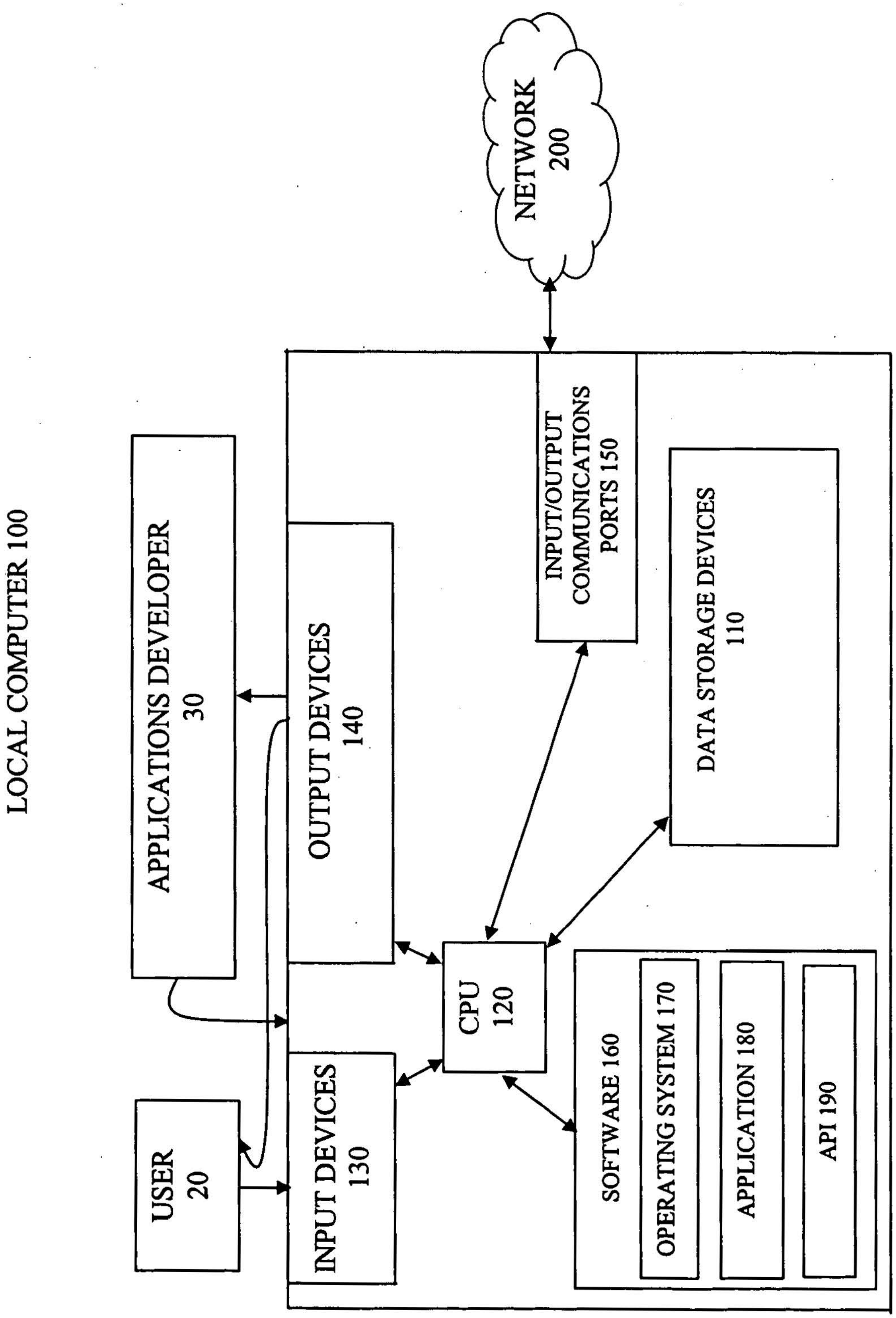

LOCAL COMPUTER 100
APPLICATIONS DEVELOPER 30
USER 20
INPUT DEVICES 130
OUTPUT DEVICES 140
CPU 120
INPUT/OUTPUT COMMUNICATIONS PORTS 150
DATA STORAGE DEVICES 110
SOFTWARE 160
OPERATING SYSTEM 170
APPLICATION 180
API 190
NETWORK 200

FIG. 3

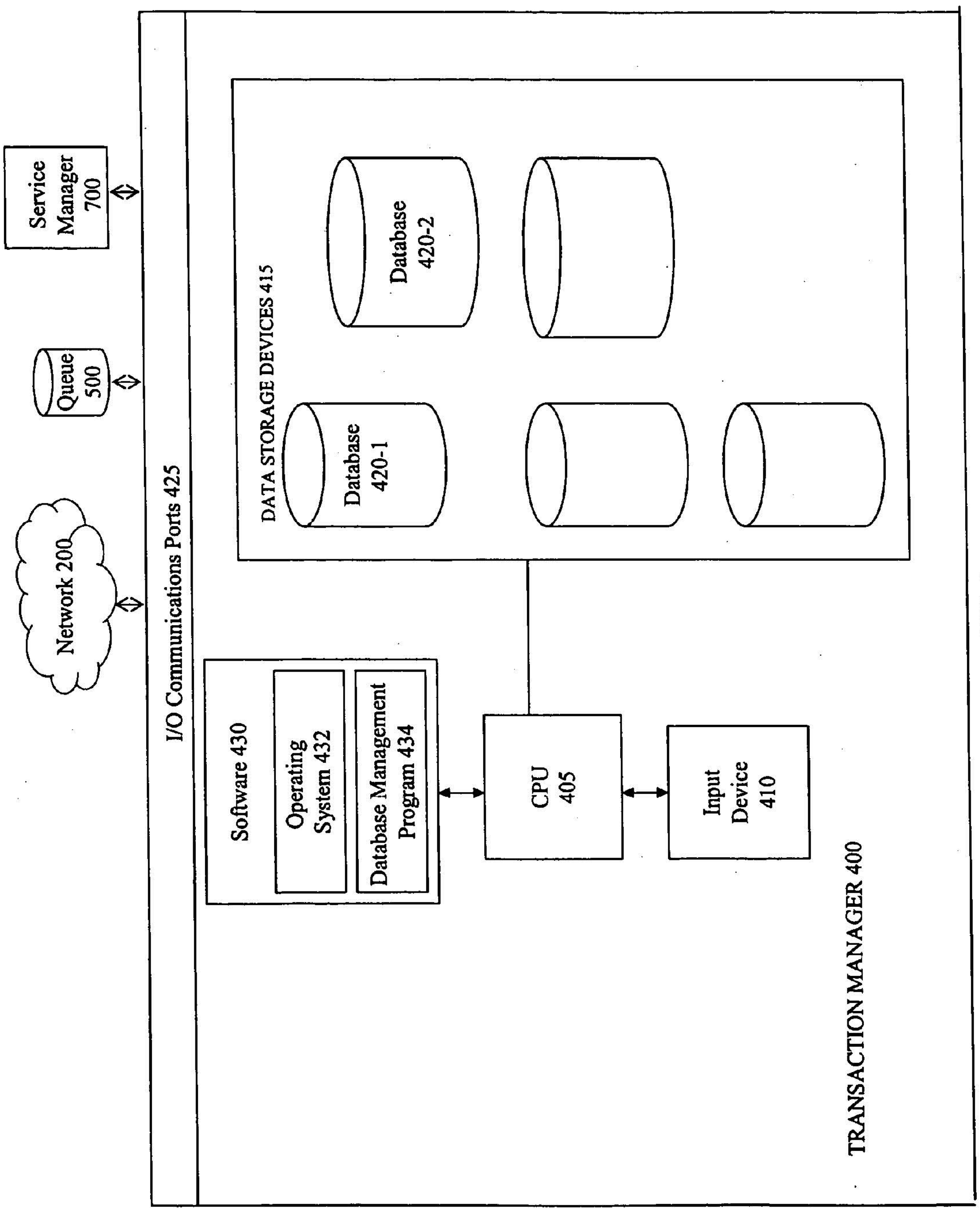

Service Manager 700
Queue 500
Network 200
I/O Communications Ports 425
DATA STORAGE DEVICES 415
Database 420-2
Database 420-1
Software 430
Operating System 432
Database Management Program 434
CPU 405
Input Device 410
TRANSACTION MANAGER 400

FIG. 4

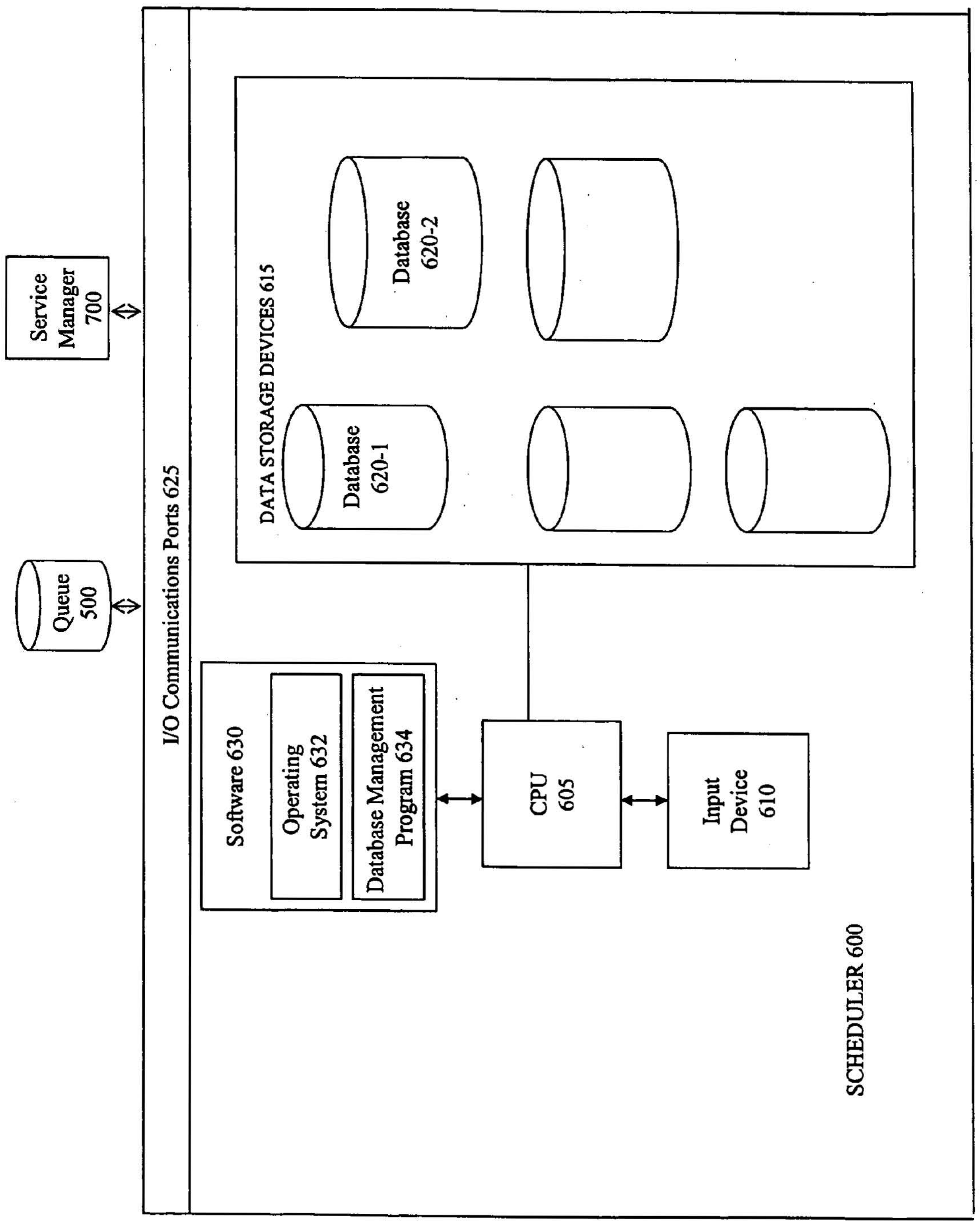

Service Manager 700
Queue 500
I/O Communications Ports 625
DATA STORAGE DEVICES 615
Database 620-1
Database 620-2
Software 630
Operating System 632
Database Management Program 634
CPU 605
Input Device 610
SCHEDULER 600

FIG. 5

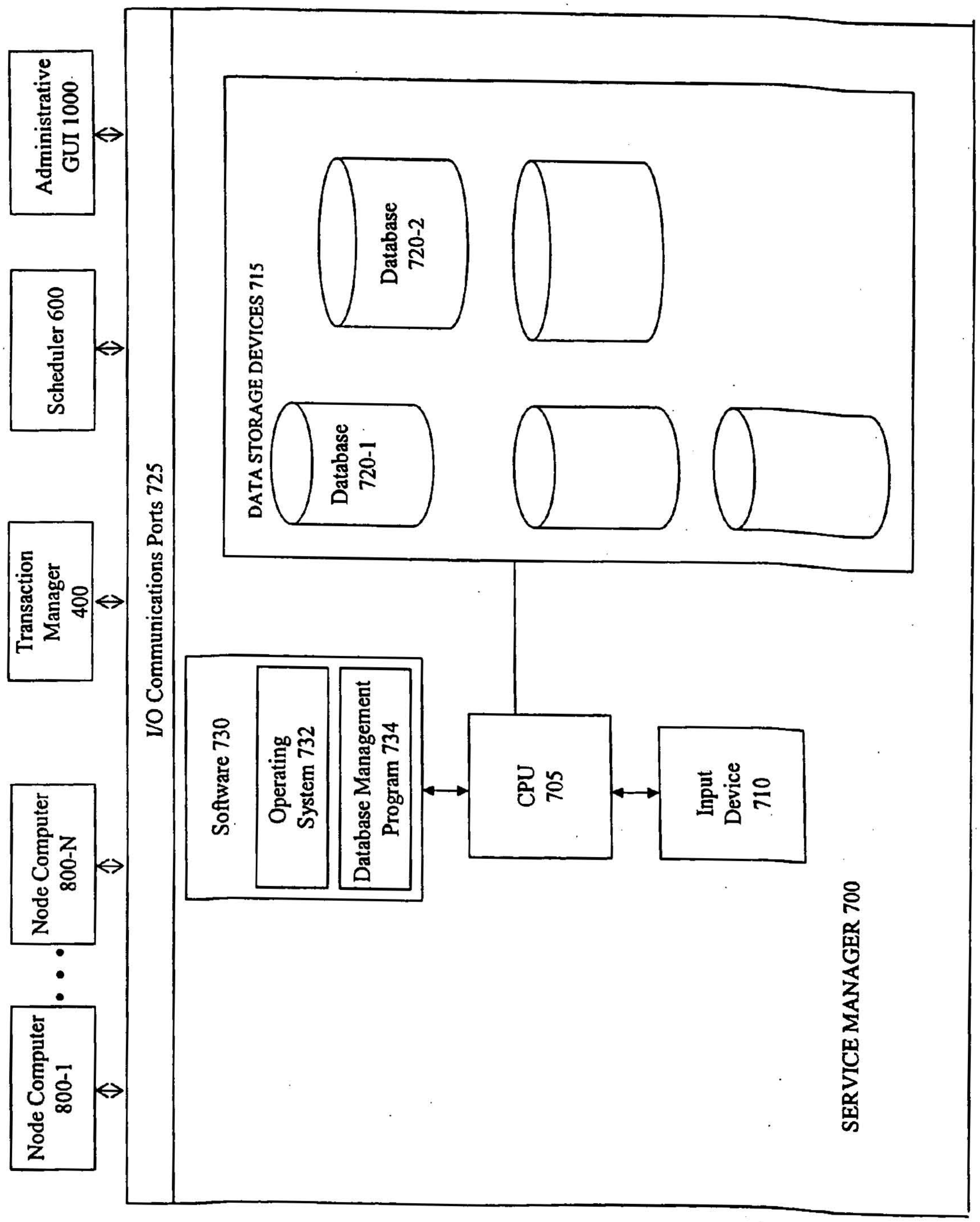

Node Computer 800-1
Node Computer 800-N
Transaction Manager 400
Scheduler 600
Administrative GUI 1000
I/O Communications Ports 725
Software 730
Operating System 732
Database Management Program 734
CPU 705
Input Device 710
DATA STORAGE DEVICES 715
Database 720-1
Database 720-2
SERVICE MANAGER 700

FIG. 6

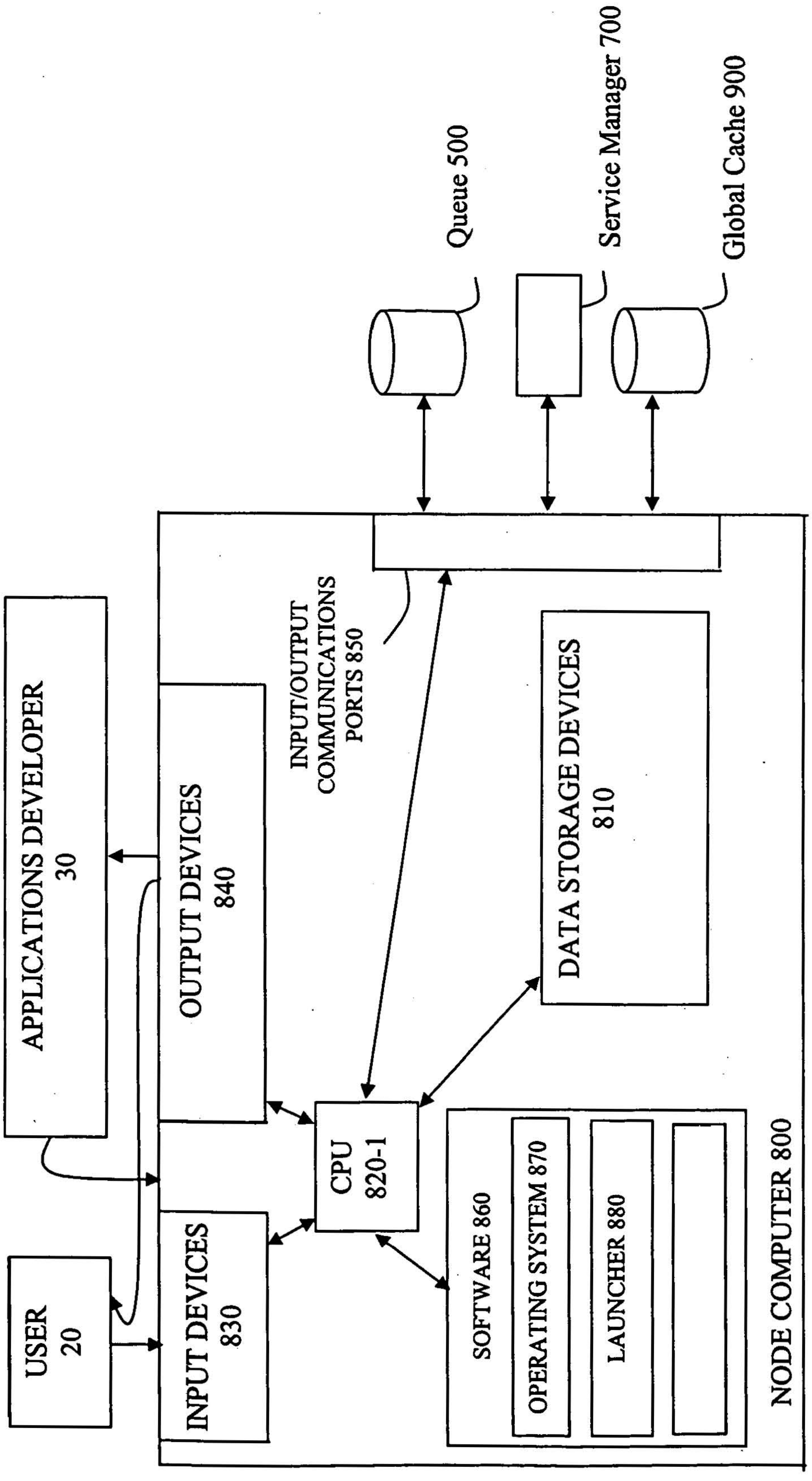

Queue 500
Service Manager 700
Global Cache 900
APPLICATIONS DEVELOPER 30
USER 20
INPUT/OUTPUT COMMUNICATIONS PORTS 850
OUTPUT DEVICES 840
DATA STORAGE DEVICES 810
INPUT DEVICES 830
CPU 820-1
SOFTWARE 860
OPERATING SYSTEM 870
LAUNCHER 880
NODE COMPUTER 800

FIG. 7

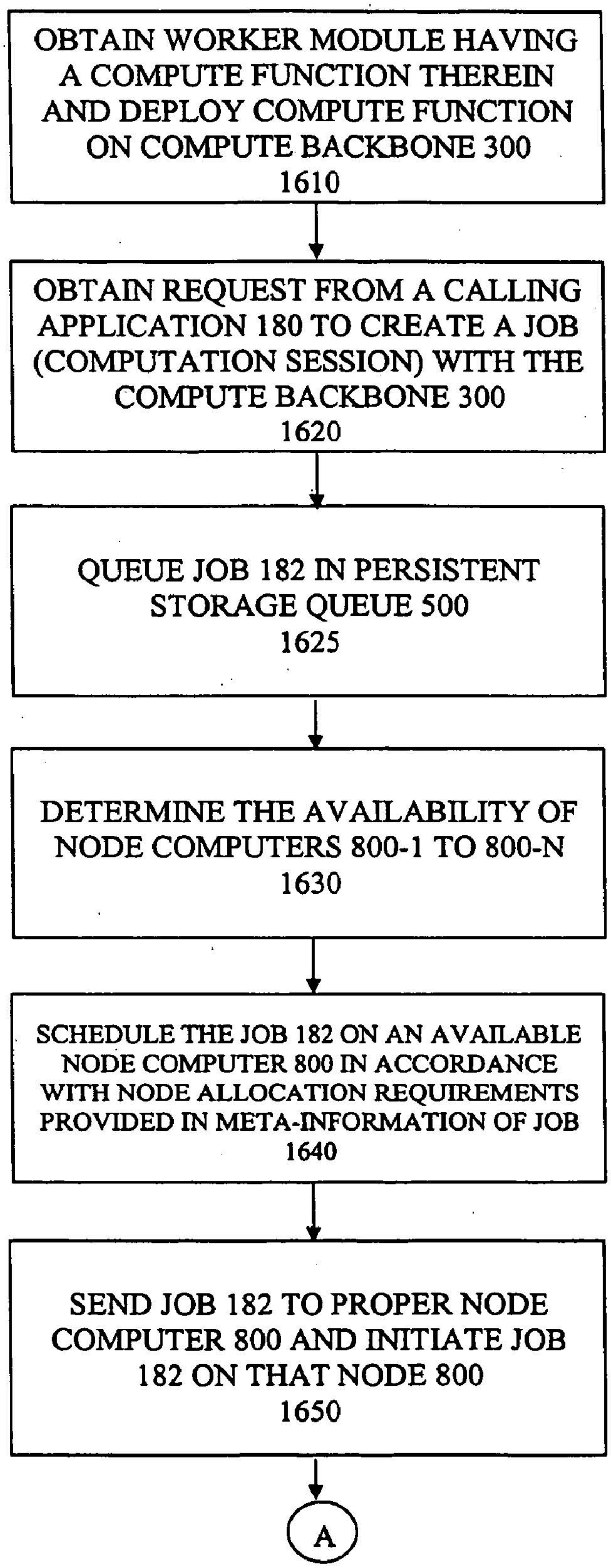

OBTAIN WORKER MODULE HAVING A COMPUTE FUNCTION THEREIN AND DEPLOY COMPUTE FUNCTION ON COMPUTE BACKBONE 300
1610
OBTAIN REQUEST FROM A CALLING APPLICATION 180 TO CREATE A JOB (COMPUTATION SESSION) WITH THE COMPUTE BACKBONE 300
1620
QUEUE JOB 182 IN PERSISTENT STORAGE QUEUE 500
1625
DETERMINE THE AVAILABILITY OF NODE COMPUTERS 800-1 TO 800-N
1630
SCHEDULE THE JOB 182 ON AN AVAILABLE NODE COMPUTER 800 IN ACCORDANCE WITH NODE ALLOCATION REQUIREMENTS PROVIDED IN META-INFORMATION OF JOB
1640
SEND JOB 182 TO PROPER NODE COMPUTER 800 AND INITIATE JOB 182 ON THAT NODE 800
1650
A

FIG. 8a

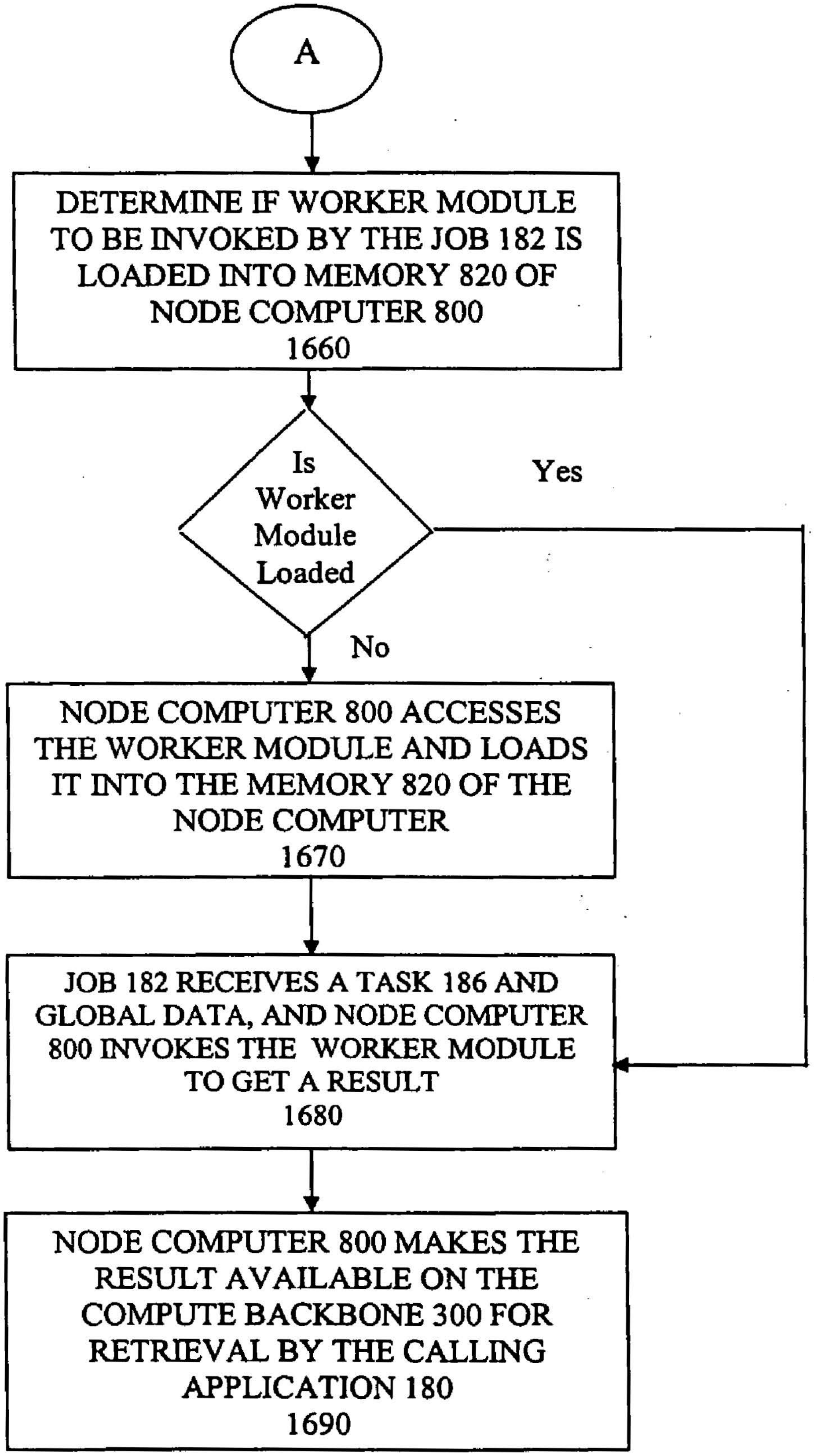

A
DETERMINE IF WORKER MODULE TO BE INVOKED BY THE JOB 182 IS LOADED INTO MEMORY 820 OF NODE COMPUTER 800
1660
Is Worker Module Loaded
Yes
No
NODE COMPUTER 800 ACCESSES THE WORKER MODULE AND LOADS IT INTO THE MEMORY 820 OF THE NODE COMPUTER
1670
JOB 182 RECEIVES A TASK 186 AND GLOBAL DATA, AND NODE COMPUTER 800 INVOKES THE WORKER MODULE TO GET A RESULT
1680
NODE COMPUTER 800 MAKES THE RESULT AVAILABLE ON THE COMPUTE BACKBONE 300 FOR RETRIEVAL BY THE CALLING APPLICATION 180
1690

FIG. 8b

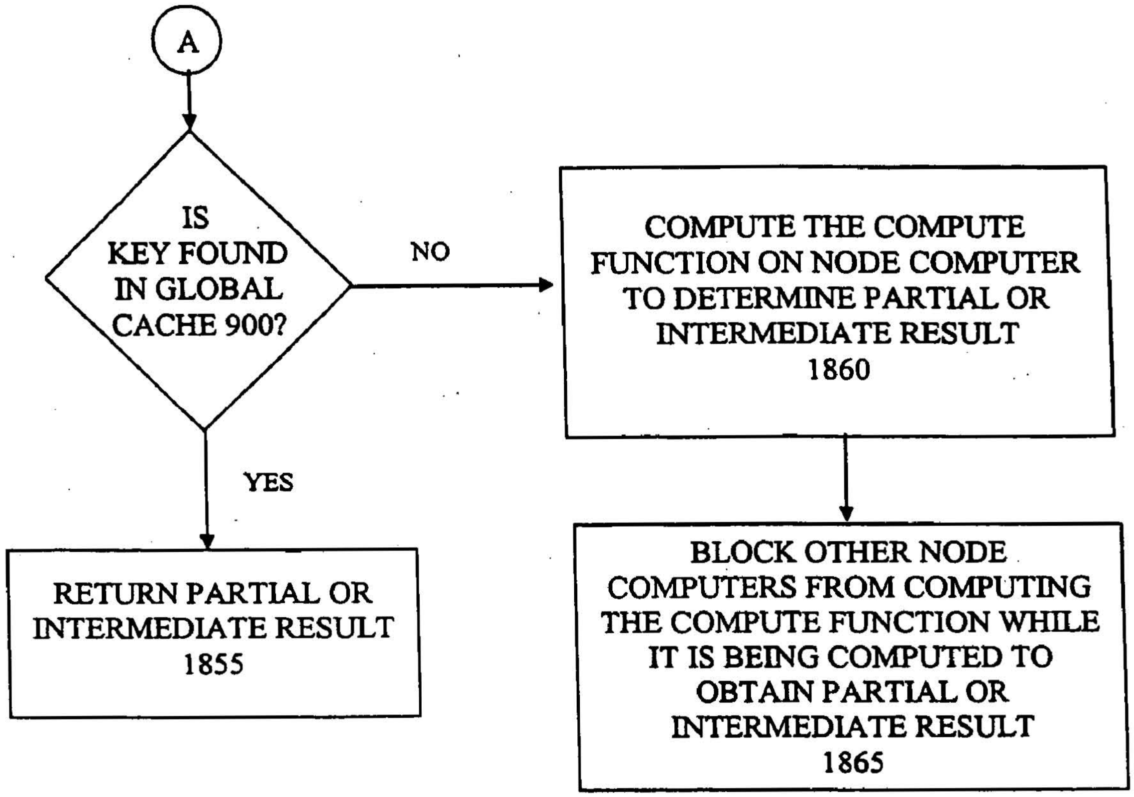

A
IS
KEY FOUND
IN GLOBAL
CACHE 900?
NO
YES
COMPUTE THE COMPUTE
FUNCTION ON NODE COMPUTER
TO DETERMINE PARTIAL OR
INTERMEDIATE RESULT
1860
RETURN PARTIAL OR
INTERMEDIATE RESULT
1855
BLOCK OTHER NODE
COMPUTERS FROM COMPUTING
THE COMPUTE FUNCTION WHILE
IT IS BEING COMPUTED TO
OBTAIN PARTIAL OR
INTERMEDIATE RESULT
1865

FIG. 10b

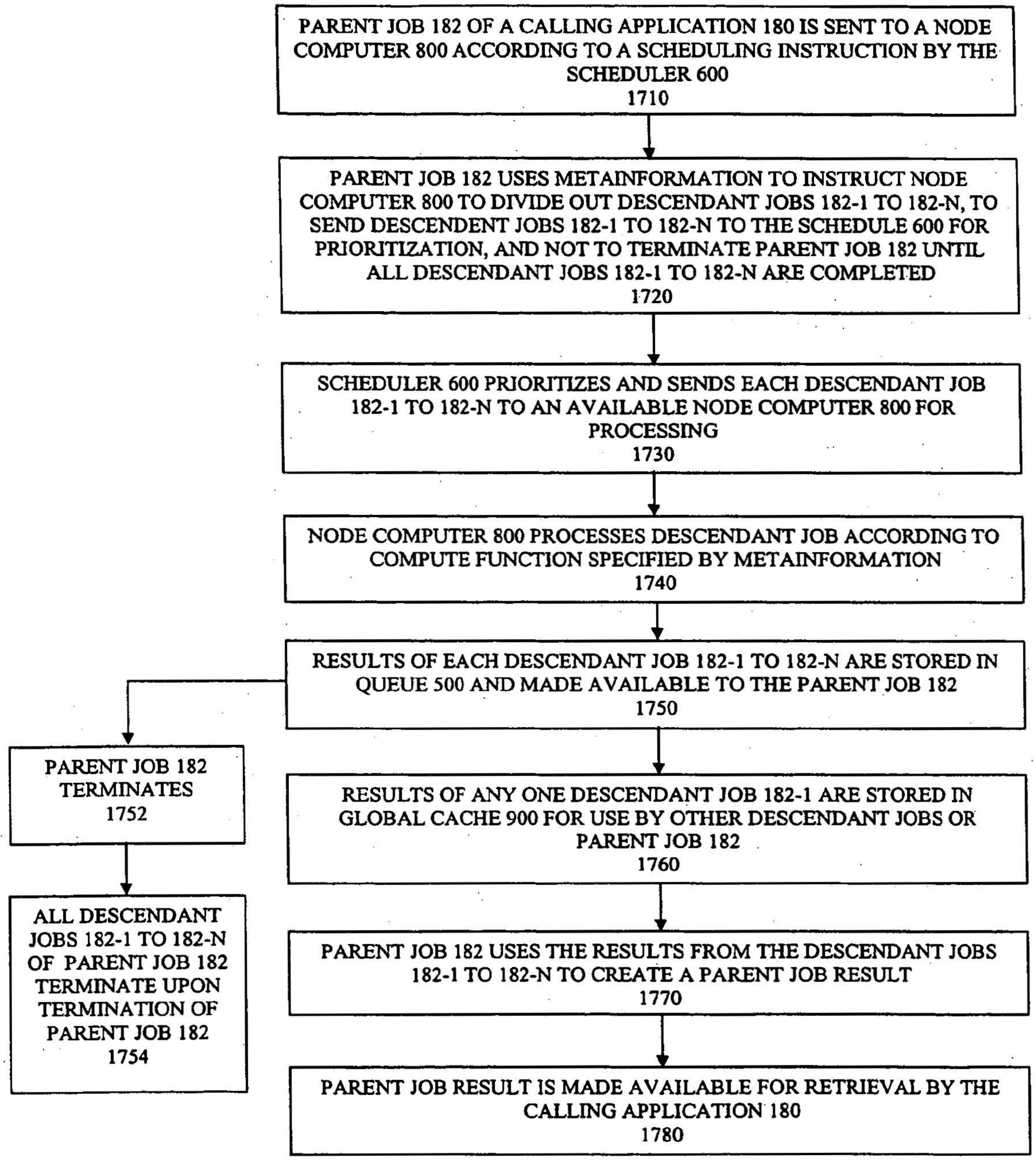

PARENT JOB 182 OF A CALLING APPLICATION 180 IS SENT TO A NODE COMPUTER 800 ACCORDING TO A SCHEDULING INSTRUCTION BY THE SCHEDULER 600
1710
PARENT JOB 182 USES METAINFORMATION TO INSTRUCT NODE COMPUTER 800 TO DIVIDE OUT DESCENDANT JOBS 182-1 TO 182-N, TO SEND DESCENDENT JOBS 182-1 TO 182-N TO THE SCHEDULE 600 FOR PRIORITIZATION, AND NOT TO TERMINATE PARENT JOB 182 UNTIL ALL DESCENDANT JOBS 182-1 TO 182-N ARE COMPLETED
1720
SCHEDULER 600 PRIORITIZES AND SENDS EACH DESCENDANT JOB 182-1 TO 182-N TO AN AVAILABLE NODE COMPUTER 800 FOR PROCESSING
1730
NODE COMPUTER 800 PROCESSES DESCENDANT JOB ACCORDING TO COMPUTE FUNCTION SPECIFIED BY METAINFORMATION
1740
RESULTS OF EACH DESCENDANT JOB 182-1 TO 182-N ARE STORED IN QUEUE 500 AND MADE AVAILABLE TO THE PARENT JOB 182
1750
PARENT JOB 182 TERMINATES
1752
ALL DESCENDANT JOBS 182-1 TO 182-N OF PARENT JOB 182 TERMINATE UPON TERMINATION OF PARENT JOB 182
1754
RESULTS OF ANY ONE DESCENDANT JOB 182-1 ARE STORED IN GLOBAL CACHE 900 FOR USE BY OTHER DESCENDANT JOBS OR PARENT JOB 182
1760
PARENT JOB 182 USES THE RESULTS FROM THE DESCENDANT JOBS 182-1 TO 182-N TO CREATE A PARENT JOB RESULT
1770
PARENT JOB RESULT IS MADE AVAILABLE FOR RETRIEVAL BY THE CALLING APPLICATION 180
1780

FIG. 9

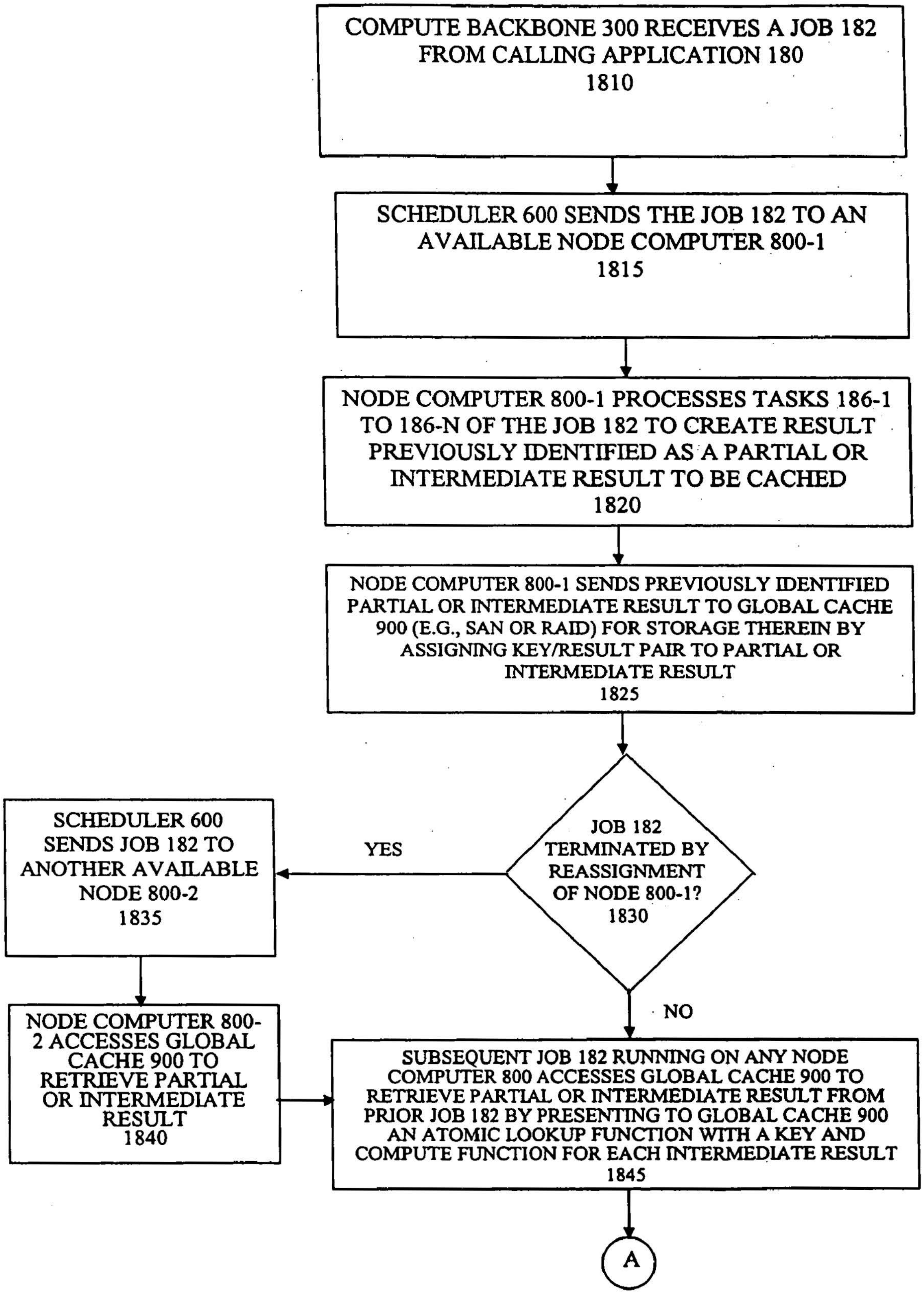

COMPUTE BACKBONE 300 RECEIVES A JOB 182 FROM CALLING APPLICATION 180
1810
SCHEDULER 600 SENDS THE JOB 182 TO AN AVAILABLE NODE COMPUTER 800-1
1815
NODE COMPUTER 800-1 PROCESSES TASKS 186-1 TO 186-N OF THE JOB 182 TO CREATE RESULT PREVIOUSLY IDENTIFIED AS A PARTIAL OR INTERMEDIATE RESULT TO BE CACHED
1820
NODE COMPUTER 800-1 SENDS PREVIOUSLY IDENTIFIED PARTIAL OR INTERMEDIATE RESULT TO GLOBAL CACHE 900 (E.G., SAN OR RAID) FOR STORAGE THEREIN BY ASSIGNING KEY/RESULT PAIR TO PARTIAL OR INTERMEDIATE RESULT
1825
JOB 182 TERMINATED BY REASSIGNMENT OF NODE 800-1?
1830
YES
SCHEDULER 600 SENDS JOB 182 TO ANOTHER AVAILABLE NODE 800-2
1835
NODE COMPUTER 800-2 ACCESSES GLOBAL CACHE 900 TO RETRIEVE PARTIAL OR INTERMEDIATE RESULT
1840
NO
SUBSEQUENT JOB 182 RUNNING ON ANY NODE COMPUTER 800 ACCESSES GLOBAL CACHE 900 TO RETRIEVE PARTIAL OR INTERMEDIATE RESULT FROM PRIOR JOB 182 BY PRESENTING TO GLOBAL CACHE 900 AN ATOMIC LOOKUP FUNCTION WITH A KEY AND COMPUTE FUNCTION FOR EACH INTERMEDIATE RESULT
1845
A

FIG. 10a

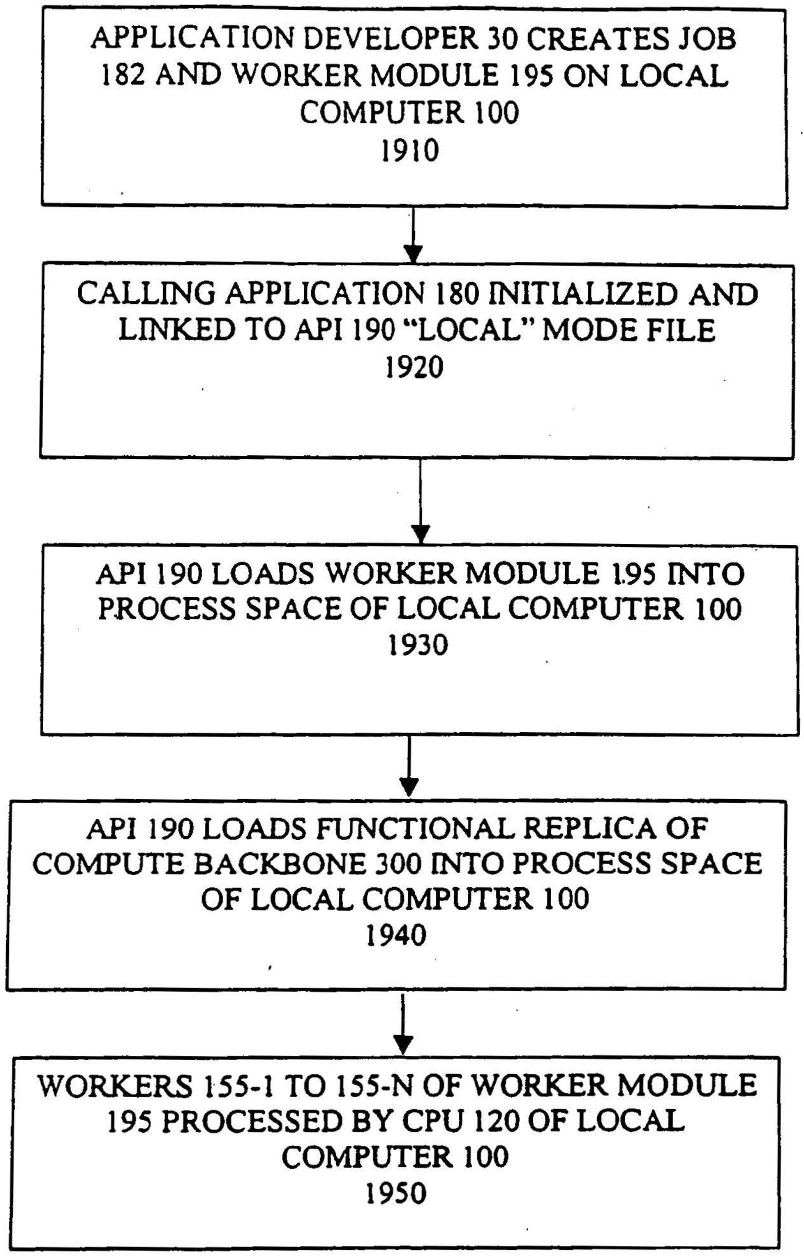

APPLICATION DEVELOPER 30 CREATES JOB 182 AND WORKER MODULE 195 ON LOCAL COMPUTER 100
1910
CALLING APPLICATION 180 INITIALIZED AND LINKED TO API 190 "LOCAL" MODE FILE
1920
API 190 LOADS WORKER MODULE 195 INTO PROCESS SPACE OF LOCAL COMPUTER 100
1930
API 190 LOADS FUNCTIONAL REPLICA OF COMPUTE BACKBONE 300 INTO PROCESS SPACE OF LOCAL COMPUTER 100
1940
WORKERS 155-1 TO 155-N OF WORKER MODULE 195 PROCESSED BY CPU 120 OF LOCAL COMPUTER 100
1950

FIG. 11

SYSTEM AND METHOD FOR DIVIDING COMPUTATIONS

BACKGROUND

[0001] I. Field of the Invention

[0002] The present invention relates to the structure and operation of computing systems, and more particularly, to distributed computing systems and methods of operating such systems.

[0003] II. Description of the Related Art

[0004] Certain organizations have a need for high performance computing resources. For example, a financial institution may use such resources to perform risk management modeling of the valuations for particular instruments and portfolios at specified states of the world. As another example, a pharmaceutical manufacturer may use high performance computing resources to model the effects, efficacy and/or interactions of new drugs it is developing. As a further example, an oil exploration company may evaluate seismic information using high performance computing resources.

[0005] One conventional computing system includes a mainframe computer attached to an individual user terminal by a network connection. Using the terminal, a user may instruct the mainframe computer to execute a command. In this conventional system, almost all data storage and processing functionality resides on the mainframe computer, while relatively little memory or processing capability exists at the terminal. This terminal/mainframe architecture may not, however, allow computations requested by a user to be computed rapidly or automatically.

[0006] The open systems interconnection (OSI) model describes one conceptual network architecture represented by seven functional layers. In this model, the functions of a networking system in a data communications network are reflected as a set of seven layers, including a physical layer, data link layer, network layer, transport layer, session layer, presentation layer and application layer. One or more entities within each layer implement the functionality of the layer. Each entity provides facilities for use only by the layer above it, and interacts directly only with the layer below it. **FIG. 1** depicts the seven functional layers of the OSI model.

[0007] The physical layer describes the physical characteristics of hardware components used to form a network. For example, the size of cable, the type of connector, and the method of termination are defined in the physical layer.

[0008] The data link layer describes the organization of the data to be transmitted over the particular mechanical/electrical/optical devices described in the physical layer. For example, the framing, addressing and check summing of Ethernet packets is defined in the data link layer.

[0009] The network layer describes how data is physically routed and exchanged along a path for delivery from one node of a network to another. For example, the addressing and routing structure of the network is defined in this layer.

[0010] The transport layer describes means used to ensure that data is delivered from place to place in a sequential, error-free, and robust (i.e., no losses or duplications) condition. The complexity of the transport protocol is defined by the transport layer.

[0011] The session layer involves the organization of data generated by processes running on multiple nodes of a network in order to establish, use and terminate a connection between those nodes. For example, the session layer describes how security, name recognition and logging functions are to take place to allow a connection to be established, used and terminated.

[0012] The presentation layer describes the format the data presented to the application layer must possess. This layer translates data from the format it possesses at the sending/receiving station of the network node to the format it must embody to be used by the application layer.

[0013] The application layer describes the service made available to the user of the network node in order to perform a particular function the user wants to have performed. For example, the application layer implements electronic messaging (such as "e-mail") or remote file access.

[0014] In certain conventional high performance computing systems designed using the OSI model, the hardware used for computation-intensive processing may be dedicated to only one long-running program and, accordingly, may not be accessible by other long running programs. Moreover, it may be difficult to easily and dynamically reallocate the computation-intensive processing from one long running program to another. In the event processing resources are to be reallocated, a program currently running on a conventional high performance computer system typically must be terminated and re-run in its entirety at a later time.

SUMMARY OF THE INVENTION

[0015] In one aspect, the invention features a method including receiving, for computation by a node computing device of a distributed computing system, a parent job configured to produce one or more descendant jobs, wherein the node computing device is one of a plurality of node computing devices of the distributed computing system. Such a method also includes scheduling computation of the parent job on the node computing device. In accordance with such an aspect, the distributed computing system further includes a scheduler server configured to selectively reschedule computation of a job other than the parent job from any one of said plurality of node computing devices to another of the node computing devices, and to receive data descriptive of an indication that the parent job is not to be rescheduled unless each of the descendant jobs is completed or terminated. According to such an aspect, the method further includes preventing rescheduling of the parent job unless each of the descendant jobs is completed or terminated.

[0016] In another aspect, the invention features a distributed computing system including a plurality of node computing devices, means for receiving, for computation by at least one of the node computing devices, a parent job configured to produce one or more descendant jobs. Such a system also includes means for scheduling computation of the parent job on the node computing device. In accordance with such an aspect, the means for scheduling is further configured to selectively reschedule computation of a job other than the parent job from any one of the plurality of node computing devices to another of the node computing devices, and to receive data descriptive of an indication that the parent job is not to be rescheduled unless each of the descendant jobs is completed or terminated. According to such an aspect, the distributed computing system further includes means for preventing rescheduling of the parent job unless each of the descendant jobs is completed or terminated.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] Features and other aspects of the invention are explained in the following description taken in conjunction with the accompanying drawings, wherein:

[0018] **FIG. 1** depicts the seven functional layers of the open systems interconnection (OSI) model;

[0019] **FIG. 2** illustrates a system **10** including a compute backbone **300** according to one embodiment of the present invention;

[0020] **FIG. 3** illustrates certain components of one embodiment of a local computer **100** of the system **10** shown in **FIG. 2**;

[0021] **FIG. 4** illustrates certain components of one embodiment of a transaction manager **400** of the system **10** shown in **FIG. 2**;

[0022] **FIG. 5** illustrates certain components of one embodiment of a scheduler **600** of the system **10** shown in **FIG. 2**;

[0023] **FIG. 6** illustrates certain components of one embodiment of a service manager **700** of the system **10** shown in **FIG. 2**;

[0024] **FIG. 7** illustrates certain components of one embodiment of a node computer **800** of the system **10** shown in **FIG. 2**;

[0025] **FIGS. 8***a* and **8***b* illustrate one embodiment of a method of executing a computing application using the system shown in **FIG. 2**.

[0026] **FIG. 9** illustrates one embodiment of a method of distributing computations using the system **10** shown in **FIG. 2**;

[0027] **FIGS. 10***a* and **10***b* illustrate one embodiment of a method of caching results using the system **10** shown in **FIG. 2**; and

[0028] **FIG. 11** illustrates one embodiment of a method of debugging using the system **10** shown in **FIG. 2**.

[0029] It is to be understood that the drawings are exemplary, and are not limiting.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0030] Various embodiments of the present invention will now be described in greater detail with reference to the drawings.

I. System Embodiments of the Invention

[0031] **FIG. 2** illustrates certain components of one embodiment of a system **10** of the present invention, which may generally include a number of local computers **100-1** to **100**-N in communication, via a network **200**, with a compute backbone **300**.

[0032] A function of this embodiment of the system **10** is to service parametric computation requests of various users **20** or groups of users. In particular, such a system **10** may allow each user **20** access to a service on a common infrastructure for performing compute dense calculations by dynamically allocating a portion of the compute backbone **300** infrastructure to the user **20** for processing of each user's **20** distinct application. A system **10** of one embodiment may include software that allows compute intensive applications to queue, schedule and prioritize their calculations on the infrastructure. In addition, the infrastructure and software of such an embodiment may operate to manage resource allocation, authentication, job distribution, data flow and fault tolerance. In accordance with this system **10**, distinct applications may each connect to the compute backbone **300** infrastructure, which may perform several operations including prioritizing compute requests from the applications according to a policy (predetermined or otherwise), allocating hardware and software resources, assigning compute requests to a proper computation resource, and returning results to the applications.

[0033] A. Local Computer **100**

[0034] In the embodiment depicted in **FIGS. 2 and 3**, each local computer **100** may generally include one or more data storage devices **110**, a central processing unit (CPU) **120**, one or more input devices **130**, one or more output devices **140**, input/output (I/O) communications ports **150**, and other hardware components (not shown) which facilitate performance of the functions of the local computer **100** and/or the system **10** as described herein. In one embodiment, the hardware devices of a local computer **100** may be in communication with one another by a shared data bus and/or by dedicated connections (not shown). In addition, a number of software components **160** may run on each local computer **100**.

[0035] A local computer **100-1** of one embodiment may be, for example, a shared memory multiprocessor machine made by Sun Microsystems configured to run programs created using the Smalltalk programming language. Another embodiment of a local computer **100-2** may be an IBM machine running programs created using the C programming language. Yet another embodiment of a local computer **100-3** may be an SGI machine running programs using the C++ and/or Java programming languages. A further embodiment of a local computer **100-4** may include a composition of a number of separate devices.

[0036] The data storage devices **10** of one embodiment may include one or more hard disk drives. However, it is to be understood that data storage devices **10** such as RAM, ROM, CD-ROM, DVD-ROM, solid state drive, floppy disk-drive or combinations thereof may also be included in the embodiment shown in **FIG. 3**, or in certain other appropriate embodiments. One embodiment of a local computer **100-1** may include input device(s) **130** (e.g., keyboard, pointing/selecting device such as a mouse or track ball, floppy disk-drive, scanner and/or touch screen interface) that may enable a user **20** and/or applications developer **30** of the system **10** to provide information and instructions for storage in the local computer **100** and use in operation of the system **10**. An embodiment of a local computer **100-1** may also include output devices **140** (e.g., printer, display device, floppy disk-drive and/or computer monitor) that may enable a user **20** and/or applications developer **30** to receive, for further manipulation and/or storage, information generated using the local computer **100** and/or the system **10**. The I/O communications ports **150** of a local computer **100-1** of one embodiment may be serial and parallel, and may be configured to include multiple communications channels for simultaneous connections. The software components **160** may include an operating system **170** (e.g., Linux, Unix, Microsoft Windows NT), one or more user interface tools **175**, calling applications **180**, and an application program interface (API) **190**. One embodiment of the system **10** may include ten or more local computers **100-1** to **100**-N.

[**0037**] i. Calling Application **180**

[**0038**] In one embodiment, a calling application **180** may be a computer program that contains logic to achieve or produce an outcome for a user **20**. The software architecture of certain applications may conceptually consist of four layers: user interface and ad hoc calculation tools; logic; persistence; and high performance computing. The user **20** may send certain computation intensive portions of a particular calling application **180** (i.e., the high performance computing layer) to the compute backbone **300** for processing rather than have the local computer **100** process those computation intensive portions. In accordance with one embodiment, the user **20** may do so by (i) creating one or more worker modules **195-1** to **195**-N (e.g., shared libraries, executable files compliant with a compute backbone **300**, Java archive files and/or other archive files), each of which contains one or more compute functions or engines called "workers"**155-1** to **155**-N, (ii) deploying the worker modules **195-1** to **195**-N on the compute backbone **300**, and (iii) sending to the compute backbone **300** a job **182** that requests the compute backbone **300** to perform a computation using a worker **155** contained in a worker module **195** that has been deployed on the compute backbone **300**. A worker **155** may be constructed to conform to and operate with the API **190**, and may conceptually "plug" into the infrastructure of the compute backbone **300** (in particular, to the launcher **880** as described below in section v.). A compute function may be implemented in a number of ways including, without limitation, as a function, as a class method or as an executable constructed to be compatible with the compute backbone **300**. In accordance with one embodiment, a worker **155** may be capable of staying initialized after completing a computation in order to handle additional compute requests should the scheduler **600** send such requests to the node computer **800** on which the worker **155** is invoked.

[**0039**] According to one embodiment, a worker **155** may be capable of computing tasks **186-1** to **186**-N once loaded onto the compute backbone **300**. For example, a worker **155** may be a function that takes task inputs and returns a task output or an error indication. Furthermore, a worker **155** may itself create a job **182** and schedule tasks **186-1** to **186**-N with the compute backbone **300**, thereby further subdividing computations to be performed.

[**0040**] A job **182** may be conceptualized as a means for opening or establishing a computation session with the infrastructure of the compute backbone **300**. In one embodiment, a job **182** may include and supply to the compute backbone **300** certain defining requirements or parameters for a computation session. In particular, one embodiment of a job **182** may include meta-information, such as an identification of a particular worker **155** to be used with the job. In one embodiment, meta-information supplied by a job **182** identifies only one worker **155** such that all jobs **182-1** to **182**-N on the compute backbone may have a generally homogeneous format. In another embodiment, meta-information supplied by a job **182** may identify more than one worker **155-1** to **155**-N.

[**0041**] Other optional meta-information may include information about the priority of the job **182** in relation to other jobs, a specification of minimal hardware requirements (e.g., minimum RAM and/or CPU power) for the job **182**, a specification of a minimum number of nodes to be allocated in order for the particular job **182** to be run properly or efficiently, the amount of debugging information the job **182** is to provide while it is running, and task logic to control sequencing and control of task computation (e.g., fail all tasks if one task fails, one task is dependent upon another task).

[**0042**] According to one embodiment, certain meta-information may be changed while a job **182** is running. For example, the priority of the job **182** may be adjusted by a user **20** without terminating or suspending the job **182**. As another example, a user **20** may modify the amount of debugging information the job is to provide while it is running.

[**0043**] In one embodiment, a job **182** may also contain one or more tasks **186** and inputs which collectively represent a unit of computational work to be performed by a processor. Such inputs may include optional global data. A particular worker **155** of a worker module **195** deployed on the compute backbone **300** may perform each task **186-1** to **186**-N. Global data and task inputs **187-1** to **187**-N may combine to represent the inputs to a particular computation. For example, a job **182** may be defined to compute the value of a number of financial instruments based on the market conditions at closing time on a particular trading day. A user **20** may configure the job **182** such that the global data for the job **182** defines the market conditions at closing, and each instrument may be represented by a separate task **186**. In such a case, the task inputs **187-1** to **187**-N and global data would be supplied to generate task output **189**. However, inputs (e.g., global data and/or task inputs **187-1** to **187**-N) need not be provided to a job **182** at the time the job **182** is created. In addition, tasks **186-1** to **186**-N need not be supplied at the time of job **182** creation. A job **182** also may have a dynamic collection of one or more tasks **186-1** to **186**-N.

[**0044**] A task **186** may be an encapsulation of a single computation to be performed by the compute backbone **300**. A task **186** has an input object **187** (i.e., the input needed for a calculation), and on success it will have an output object or an error indication **189**. At any point in time a task **186** also has a state **188**, such as an indication of whether the task **186** has been completed or not (e.g., queued, running, completed, rescheduled, suspended, or error), and produce log data as generated by the worker **155**. In accordance with one embodiment, a worker **155** on the compute backbone **300** loads a worker module **195**, performs a requested computation, and creates task output **189**.

[**0045**] In one embodiment, calling applications **180-1** to **180**-N running on the local computers **100-1** to **100**-N are programmed to interface with the compute backbone **300**. In particular, a calling application **180** running on a particular local computer **100** is compatible with the API **190** also running on that local computer **100**. For example, a calling application **180** created in C programming language may be compatible with the C language API **190** running on a particular local computer **100**. In such an example, a portion of the API **190** may communicate with both the calling application **180** and the compute backbone **300** in the following manner. First, a calling application **180** may send a request, in C language, for something to be done by the compute backbone **300** (e.g., a request for a computation to be performed or for a result to be retrieved). The API **190** may translate the C language request into, for example, a language independent protocol such as an XML/HTTP protocol request, and then send it to the compute backbone **300**, which in turn processes the request from the calling application **180**.

[**0046**] ii. Application Program Interface **190**

[**0047**] According to one embodiment, an object oriented API **190** residing on a local computer **100** provides an interface between a calling application **180** and the compute backbone **300**. Such an API **190** may use a transparent communication protocol (e.g., SOAP, XML/HTTP or its variants) to provide communication between calling applications **180-1** to **180**-N and the compute backbone **300** infrastructure. The API **190** of one embodiment interacts with the transaction manager **400** to authenticate requests from calling applications **180-1** to **180**-N for access to the resources of the compute backbone **300**.

[**0048**] Each API **190** contains a minimal but complete set of operations (to be performed by the compute backbone **300**) that supports the job logic of the particular calling application **180**, as well as the communication patterns of the local computer **100** on which the calling application **180** is running, such that the API **190** can send computation inputs and retrieve results. Each API **190** has a client **183** embedded in the calling application **180**. The client **183** communicates with the compute backbone **300**. Each API **190** also includes a managed service component **198** that implements resource allocation, fault tolerance, user acceptance testing (UAT), and release control functions.

[**0049**] The APIs **190-1** to **190**-N shown in **FIG. 2** need not all be compatible with the same programming language. For example, one API **190-1** may be compatible with C programming language, while another API **190-2** is compatible with C++ programming language, while yet another 190-3 is compatible with Java programming language.

[**0050**] The API **190** assists a calling application **180** in finding and accessing a compute function contained in a worker module **190** deployed on the compute backbone **300**. In particular, the API **190** provides an agent or proxy responsible for performing computations on the compute backbone **300**, i.e. a worker **155**, and defines the way the computation inputs and outputs are to be communicated. The API **190** also allows users **20-1** to **20**-N (i) to schedule jobs **182-1** to **182**-N (which are associated with a particular calling application **180**) with a worker **155** that resides on an available node computer **800** of the compute backbone **300**, (ii) to query and modify the status and priority of the jobs **182-1** to **182**-N, and (iii) to terminate running jobs **182-1** to **182**-N. The API **190** may also provide workers **155-1** to **155**-N with access to global cache **900** (i.e., persistent storage) such that the workers **155-1** to **155**-N may share intermediate computational results. Furthermore, the API **190** may schedule tasks **186-1** to **186**-N synchronously or asynchronously to allow a calling application **180** to either wait for a computation to complete before continuing, or to continue and then poll for results at a later time. An API **190** of one embodiment may also facilitate the connection of separate calling applications **180-1** to **180-2** to a job **182** (e.g., one calling application **180-1** may submit inputs to a job **182** while another calling application **182-2** handles retrieval of results from the job **182**).

[**0051**] An API **190** according to one embodiment may also facilitate workers **155** themselves becoming clients of the compute backbone **300** to further decompose a particular computation request. For example, an API **190** running on a particular local computer **100** may send a request to the compute backbone **300** to compute the value of a portfolio of instruments. That API **190** may facilitate decomposition of the request into a number of separate requests which each value one instrument of the portfolio. After the value of each instrument is computed, the compute backbone **300** collects the results for delivery back to the local computer **100**.

[**0052**] One embodiment of the API **190** is capable of operating in one of two modes: "network" mode or "local" mode. In local mode, the API **190** simulates the compute backbone **300** on a local computer **100** as a closed environment. In such a mode of operation, the API **190** initializes a worker module **195** containing a worker **155** in the same process space as the job **182** making the request (i.e., on the local computer **100** in which the particular API **190** and calling application **180** reside), rather than on a node computer **800** separated from the local computer **100** by, among other things, a network **200**. In local mode, the API **190** makes all of the functions performed by the compute backbone **300** (e.g., scheduling, global caching, etc.) available to the worker **155** as if the worker **155** were being run on the compute backbone **300**. In this embodiment, the API **190** in local mode emulates to the calling application **180** all of the functions of the compute backbone **300**. Such a local mode of operation may allow a user **20** and/or applications developer **30** to debug the worker modules **195-1** to **195**-N and jobs **182-1** to **182**-N it creates, as well as perform regression and other testing and debugging in a local environment. Such a feature may form the basis for a contractual service level agreement between a client organization and an administrator for the compute backbone **300**.

[**0053**] In the event a calling application **180** may not be functioning properly when run with the compute backbone **300** infrastructure, a user **20** and/or applications developer **30** may use local mode operation according to one embodiment to isolate the source of the error. In particular, a user **20** and/or applications developer **30** may operate a debugging tool on the local computer **100**. Moreover, a user **20** and/or applications developer **30** may use local mode operation according to one embodiment to verify that the compute backbone **300** is performing the functions and delivering the level of service the user **20** and/or applications developer **30** expects.

[**0054**] B. Network **200**

[**0055**] In the embodiment depicted in **FIG. 2**, the network **200** is a local area network (LAN). Although the network **200** of the embodiment shown in **FIG. 2** is a single LAN, in alternative embodiments, connections between local computers **100-1** to **100**-N and the compute backbone **300** may be of different types, including a connection over a telephone line, a direct connection, an Internet, a wide area network (WAN), an intranet or other network or combination of the aforementioned connections that is capable of communicating data between hardware and/or software devices. The network of the embodiment shown in **FIG. 2** may have a minimum data transfer rate of 100 megabytes per second (MBps), and an optimal data transfer rate of greater than 1 GBps. More than one local computer **100-1** to **100**-N at a time may communicate with the compute backbone **300** over the network **200**.

[0056] In one embodiment, communication over the network **200** between a particular local computer **100** and the compute backbone **300** may be accomplished using a communications protocol such as XML/HTTP, simple object access protocol (SOAP), XMLRPC, transfer control protocol/internet protocol (TCP/IP), file transfer protocol (FTP), or other suitable protocol or combination of protocols.

[0057] Using the network **200**, a local computer **100** may request information from the compute backbone **300** (in particular, the transaction manager **400**, described below) by sending a request in a particular communication protocol (e.g., a hypertext transfer protocol (HTTP) request). For example, a local computer **100** shown in **FIG. 3** may request access to the compute backbone **300** to process a job **182**. When the local computer **100** contacts the transaction manager **400** (which, in one embodiment, is a server) of the compute backbone **300**, the local computer **100** asks the transaction manager **400** for information (e.g., a file of computation results) by building a message with a compatible language and sending it. After processing the request, the transaction manager **400** sends the requested information to the local computer **100** in the form of the particular communication protocol. Software **160** running on the local computer **100** may then interpret the information sent by the transaction manager **400** and provide it to the user **20** (e.g., display it on an output device **140** such as a computer monitor). In one embodiment, the transaction manager **400** may communicate with a local computer **100** using a secure protocol (e.g., secure socket layer (SSL)).

[0058] C. Compute Backbone **300**

[0059] According to one embodiment, the compute backbone **300** and a corresponding API **190** enables a number of users **20-1** to **20**-N each running, for example, a number of different and completely independent calling applications to be processed dynamically on a single pool of distributed processing resources. Such an embodiment of the compute backbone **300** may collect computation requests from calling applications **180-1** to **180**-N, invoke those requests on appropriate compute functions or engines (i.e., workers **155-1** to **155**-N), assemble results, and return those results to the invoking calling applications **180-1** to **180**-N.

[0060] As shown in **FIG. 2**, one embodiment of the compute backbone **300** generally includes a transaction manager **400**, a central queue **500**, a scheduler **600**, a service manager **700**, a number of node computers **800-1** to **800**-N and a global cache **900**. As depicted, the compute backbone **300** further includes user interface tools, including an administrative general user interface (GUI) **1000**, which allows a user **20** and/or applications developer **30** to monitor and troubleshoot operations of the compute backbone **300**. The compute backbone **300** of one embodiment is flexible enough to allow a request for computation resources equivalent to hundreds of CPUs to be satisfied within minutes. In addition, such a compute backbone **300** may be capable of sustaining input/output data rates sufficient to allow the loading of a global cache **900** of, for example, 250 megabytes (MB) within approximately ten seconds.

[0061] i. Transaction Manager **400**

[0062] The transaction manager **400** shown in **FIGS. 2 and 4** is a gateway to the compute backbone **300**. As such, the transaction manager **400** supports multiple types of messaging protocols to enable communication between itself and various types of local computers **100-1** to **100**-N running different calling applications **180** created in different programming languages. Using the API **190**, the transaction manager **400** also guarantees delivery of a compute request from a particular calling application **180** on a local computer **100**, and performs some transactional queue management.

[0063] In one embodiment, all communications between a local computer **100** and the transaction manager **400** are secure and involve an authentication process before access to the compute backbone **300** is granted. Such authentication assists the compute backbone **300** (in particular, the service manager **700** and administrative GUI **1000**, discussed below) in generating accurate billing information detailing a particular user's **20** usage of the resources of the compute backbone **300**, and also helps to prevent unauthorized access to the compute backbone **300**.

[0064] **FIG. 4** is a block diagram showing certain components of a transaction manager **400** according to one embodiment of the present invention. As **FIG. 4** illustrates, the transaction manager **400** of one embodiment is a server having a central processing unit (CPU) **405** that is in communication with a number of components by a shared data bus or by dedicated connections—these components include one or more input devices **410** (e.g., a CD-ROM drive and/or tape drive) which enable information and instructions to be input for storage in the transaction manager **400**, one or more data storage devices **415**, having one or more databases **420** defined therein, input/output (I/O) communications ports **425**, and software **430**. Each I/O communications port **425** has multiple communications channels for simultaneous connections with multiple local computers **100-1** to **100**-N. The software **430** includes an operating system **432** and database management programs **434** to store information and perform the operations or transactions described herein. The transaction manager **400** of one embodiment may access data storage devices **415** which may contain a number of databases **420-1** to **420**-N. Although the embodiment shown in **FIG. 4** depicts the transaction manager **400** as a single server, a plurality of additional servers (not shown) may also be included as part of the transaction manager **400**.

[0065] The transaction manager **400** of one embodiment is a Unix server which includes at least one gigabytes (GB) of memory.

[0066] ii. Queue **500**

[0067] The queue **500** shown in **FIG. 2** may perform the following functions: (i) receiving and storing jobs **182-1** to **182**-N and task inputs **187-1** to **187**-N from the transaction manager **400**; (ii) exchanging information with a scheduler **600** such that jobs **182-1** to **182**-N are routed to appropriate node computers **800-1** to **800**-N; (iii) sending computation requests to node computers **800-1** to **800**-N; and (iv) providing computation results (i.e., task outputs **189-1** to **189**-N) when polled by the transaction manager **400**. Because in some instances task outputs **189-1** to **189**-N are not deleted even after they are retrieved by a calling application **180**, it is essential to be able to store large amounts of data effectively and efficiently. The queue **500** of one embodiment may be a fault tolerant, persistent storage system responsible for receiving and storing jobs **182-1** to **182**-N and task inputs **187-1** to **187**-N from the transaction manager **400**, executing scheduling commands (i.e., routing decisions) from the scheduler **600** and sending the computation requests and necessary inputs to the node computers **800-1** to **800**-N that perform the computations, and receiving and storing task outputs **189-1** to **189**-N for retrieval. When requested by a calling application **180**, the transaction manager **400** may return the results of a computation stored in the queue **500** back to the calling applications **180-1** to **180**-N corresponding to each job **182-1** to **182**-N. In one embodiment, all information pertinent for a particular job **182** is stored, persistently, in the queue **500** at least until the job **182** has been completed or has expired.

[**0068**] The queue **500** of one embodiment may be able to handle large throughputs of requests with low latency. For example, the queue **500** of one embodiment may be able to process hundreds of thousands of requests per job **182**, each request ranging in size from a few kilobytes to hundreds of kilobytes. For normal load conditions in the compute backbone **300** infrastructure of one embodiment, the time it takes to receive a request, send it to a node computer **800**, and retrieve the result should take no more than 500 ms, with 100 ms or less being optimal. The queue **500** of one embodiment may be configured to operate with hundreds of node computers **800-1** to **800**-N, a number of transaction managers **400-1** to **400**-N and a number of schedulers **600-1** to **600**-N. Hence, the configuration of the queue **500** may be closely correlated with that of the node computers **800-1** to **800**-N, the scheduler **600** and the transaction manager **400**, each of the components adapting to work most efficiently together. In such an embodiment, the queue **500** may represent the single point of failure for the compute backbone **300**, such that the number of components downstream of the queue **500** (i.e., node computers **800-1** to **800**-N and global cache **900**) may be increased substantially without increasing the probability of a failure of the entire compute backbone **300**, even though the mean time to failure of some component downstream of the queue **500** is likely to decrease as the number of such components increases. With such an arrangement, the user **20** may be guaranteed to obtain a result from the compute backbone **300** even if all components downstream of the fault tolerant queue **500** fail and need to be replaced. In this way, the queue **500** may represent a minimum availability of the compute backbone **300**.

[**0069**] To help ensure that a job **182** sent to the compute backbone **300** is processed to completion, the queue **500** may persist certain data, including: (i) meta-information associated with a particular job **182** (e.g., job priority and an identification of a worker **155**), (ii) optional global data **188** that is to be made available to all of the computations in the job **182**, which may be supplied at the time the job **182** is created or at some later time, (iii) one or more task inputs **187-1** to **187**-N provided by the transaction manager **400** (the queue **500** may optionally delete the task inputs **187-1** to **187**-N after the computation completes), (iv) task outputs **189-1** to **189**-N generated by the computations (the queue **500** may optionally delete the task outputs **189-1** to **189**-N after retrieval by the calling application **180**), (v) in case of error, the task error output **189**, which is stored in place of the real task output **189**, and (vi) optionally, a computation log for use in debugging and/or verifying the computation results (however, even if such a computation log is generated, the calling application **180** may choose not to retrieve it). In the embodiment depicted in **FIG. 2**, the queue **500** may be, for example, a storage area network (SAN) such as an EMC Celerra File Server, a network attached storage (NAS), or a database server.

[**0070**] iii. Scheduler **600**

[**0071**] In one embodiment, the scheduler **600** of the compute backbone **300** may route incoming tasks **186** to appropriate workers **155** on the node computers **800-1** to **800**-N assigned to a particular user's **20** service. Another function of an embodiment of the scheduler **600** is to allocate an appropriate amount of computing resources to particular jobs **182-1** to **182**-N based on (1) the amount of resources allocated to a particular service and (2) the resource requirements of the jobs **182-1** to **182**-N (as communicated, for example, by the meta-information within each job **182**). For example, based on a scheduling algorithm computed by the scheduler **600**, a particular job **182** may be sent to a particular node computer **800** that is available for processing and has been assigned to a service. The scheduler **600** also may route a specific piece of work to a given node computer **800** upon request (e.g., based on meta-information contained within a job **182**). In one embodiment, the scheduler **600** may use policy and priority rules to allocate, for a particular session, the resources of multiple CPUs in a pool of node computers **800**.

[**0072**] As a user **20** monitors the progress of a particular calling application **180** running on the compute backbone **200**, the user **20** may use the scheduler **600** to dynamically reallocate and/or adjust the computing resources (e.g., CPUs on the node computers **800-1** to **800**-N) from one or more service(s) to another without entirely terminating any of the jobs **182-1** to **182**-N running on the compute backbone **300**. In particular, the scheduler **600** works with the service manager **700** to determine which node computers **800-1** to **800**-N and/or other resources can be reallocated to other services.

[**0073**] As shown in **FIGS. 2 and 5**, the scheduler **600** of one embodiment may be a server having a CPU **605** that is in communication with a number of components by a shared data bus or by dedicated connections. Such components may include one or more input devices **610** (e.g., CD-ROM drive and/or tape drive) which may enable instructions and information to be input for storage in the scheduler **600**, one or more data storage devices **615**, having one or more databases **620** defined therein, input/output (I/O) communications ports **625**, and software **630**. Each I/O communications port **625** may have multiple communication channels for simultaneous connections. The software **630** may include an operating system **632** and data management programs **634** configured to store information and perform the operations or transactions described herein. The scheduler **600** of one embodiment may access data storage devices **615** which may contain a number of databases **620-1** to **620**-N. Although the embodiment shown in **FIG. 2** depicts, the scheduler **600** as a single server, a plurality of additional servers (not shown) may also be included as part of the scheduler **600**. In an alternative embodiment, the scheduler **600** may be one or more personal computers.

[**0074**] Using routing commands from the service manager **700**, as well as the meta-information contained in each job **182**, the scheduler **600** picks the best suitable request for a particular node computer **800** and assigns the request to that node computer **800**. In the embodiment shown in **FIG. 2**, communications between the scheduler **600** and the node computers **800-1** to **800**-N passes through the queue **500**. The scheduler **600** also may communicate with the service manager **700** to take appropriate action when a node computer **800** becomes unavailable due to failure, reassignment for use by another service, suspension, or other reason. In such cases, the scheduler **600** reschedules computations running on the failed or reassigned node computer **800** so that the results from all jobs **182-1** to **182**-N sent to the compute backbone **300** are eventually completed and returned to the appropriate calling application **180**. Based on certain factors, including the load on a particular node computer **800**, the scheduler **600** may also decide to run more than one computation at a time on the node computer **800**. All the data used by the scheduler **600** may be persisted in the queue **500**, and perhaps also the service manager **700**. In one embodiment, the scheduler **600** may be forced to make, for example, hundreds of scheduling decisions per second. In certain embodiments, the scheduler **600** may also support load balancing, with more than one scheduler **600-1** to **600**-N (not shown) being assigned to a particular service.

[**0075**] The scheduler **600** may change allocations while calling applications **180-1** to **180**-N are running on the compute backbone **300**. The combination of the scheduler **600**, queue **500**, service manager **700** and global cache **900** may allow dynamic re-allocation without loss of intermediate results.

[**0076**] iv. Service Manager **700**

[**0077**] In one embodiment, the service manager **700** controls how resources on the compute backbone **300** are allocated to different users **20-1** to **20**-N. In particular, each node computer **800-1** to **800**-N provides the service manager **700** with information about its availability at any particular time. The service manager **700** of one embodiment allocates resources on the compute backbone **300** to users **20-1** to **20**-N or groups of users such that failure of one user's **20-1** calling application **180-1** will not effect another user's **20-2** calling application **180-2** running on the compute backbone **300**, even if both applications **180-1**, **180-2** are running simultaneously. To achieve this isolation, a "service" is created for each user **20** or group of users. In one embodiment, the hardware portion of the service is an encapsulation (logical or physical) of all of the resources (e.g., number and identity of node computers **800-1** to **800**-N, amount of storage capacity in the global cache **900**, amount of database storage capacity, etc.) of the compute backbone **300** that are allocated for use by a particular user **20** at a particular time. In such an embodiment, the software portion of the service includes the worker modules **195-1** to **195**-N that can perform specific computations for a particular user **20** or group of users. According to one embodiment, when a user **20** seeks to access the compute backbone **300**, an administrator allocates resources to the user **20**.

[**0078**] At any one time, a particular node computer **800** may be allocated only to one user **20**. However, any one node computer **800** allocated to a particular user **20** may run multiple calling applications **180-1** to **180**-N from the user **20** assigned to that node computer **800** during a specific time period. Furthermore, any one node computer **800** may be allocated to different users **20-1** to **20**-N during different times of the day or week. For example, one user **20-1** may have access to node computers **800-1** to **800-10** from 9:00 a.m. to 11:00 a.m. every morning, while another user **20-2** has access to node computers **800-1** to **800-3** from 11:00 a.m. to 11:30 a.m. every Monday morning, while yet another user **20-3** has access to node computers **800-1** to **800-100** from 2:00 p.m. to 2:00 a.m. every Tuesday afternoon and Wednesday morning.

[**0079**] According to one embodiment, a user **20** may be allocated (and thus guaranteed) access to a predetermined number of node computers **800-1** to **800**-N during a particular time period. In the event that some node computers **800-1** to **800**-N have not been allocated to a particular user **20** at a particular time, such unused computation resources may be allocated to one or more users **20-1** to **20**-N based on a set of criteria (e.g., one user **20-1** may be willing to pay up to a certain amount of money to secure the unallocated resources at a particular time, but will not be allocated those resources if another user **20-2** is willing to pay more). In an alternative embodiment, more elaborate resource sharing may be available such that allocated but unused resources may also be re-allocated based on a set of criteria.

[**0080**] In one embodiment, the service manager **700** monitors and accounts for all resources available on the compute backbone **300** and, in real time, provides the scheduler **600** with information about which services have been created and what specific resources have been allocated to each service. For example, a user **20** seeking to run a calling application **180** using the compute backbone must first be allocated a service, which includes, among other things, the processing capability of a specific number of specific type(s) of node computers **800-1** to **800**-N during a specific time period.

[**0081**] The service manager **700** may reclaim particular node computers **800-1** to **800**-N assigned to a particular service for use by a different service. The service manager **700** may also set limits on storage and other resources available to a service. In one embodiment, the service manager **700** collects accounting information from the node computers **800-1** to **800**-N, and makes that accounting information available for reporting by an administrative GUI **1000** in order to supply users **20-1** to **20**-N with billing and resource utilization information.

[**0082**] The service manager **700** of one embodiment persists at least the following information: (i) a complete inventory of node computers **800-1** to **800**-N and storage resources, (ii) the resources allocated to each service, (iii) the resources requested by each user **20** or group of users, and (iv) resource usage and allocation information for use by the administrative GUI **1000** in creating accounting reports for users **20-1** to **20**-N.

[0083] In one embodiment, the service manager **700** may be in direct communication with an administrative GUI **1000**, the transaction manager **400** and the scheduler **600**. In addition, the service manager **700** may receive information about the status of all node computers **800-1** to **800**-N on the compute backbone **300** (e.g., failed, unavailable, available). The administrative GUI **1000** and its user interface software allow a user **20** to directly interact with the service manager **700** to change meta-information of a job **182** (e.g., modify the priority) and perform job control actions such as suspending, terminating and restarting the job **182**. In addition, the transaction manager **400** may interact with the service manager **700** to programmatically prioritize, schedule and queue the jobs **182-1** to **182**-N associated with the calling applications **180-1** to **180**-N sent to the services of each user **20-1** to **20**-N. Once a service has been created, the service manager **700** commands the scheduler **600** to begin scheduling particular jobs **182-1** to **182**-N for processing on the node computers **800-1** to **800**-N assigned to a particular service.

[0084] In the event a node computer **800** fails or becomes otherwise unavailable for processing, the service manager **700** detects the unavailability of that node computer **800** and removes the node computer **800** from the service allocated to the user **20**. In addition, the service manager **700** prompts the scheduler **600** to re-queue the scheduling requests made previously (and/or being made currently) from the failed or unavailable node computer **800-1** to another available node computer **800-2**.

[0085] **FIG. 6** is a block diagram showing certain components of a service manager **700** according to one embodiment of the present invention. As **FIG. 6** illustrates, the service manager **700** of one embodiment is a server having a central processing unit (CPU) **705** that is in communication with a number of components by a shared data bus or by dedicated connections—these components include one or more input devices **710** (e.g., CD-ROM drive, tape drive, keyboard, mouse and/or scanner) which enable information and instructions to be input for storage in the service manager **700**, one or more data storage devices **715**, having one or more databases **720** defined therein, input/output (I/O) communications ports **725**, and software **730**. Each I/O communications port **725** has multiple communications channels for simultaneous connections with multiple local computers **100-1** to **100**-N. The software **730** includes an operating system **732** and database management programs **734** to store information and perform the operations or transactions described herein. The service manager **700** of one embodiment may access data storage devices **715** which may contain a number of databases **720-1** to **720**-N. Although the embodiment shown in **FIG. 6** depicts the service manager **700** as a single server, a plurality of additional servers (not shown) may also be included as part of the service manager **700**.

[0086] V. Node Computer **800**

[0087] In accordance with one embodiment, the node computers **800** perform computations according to scheduling commands from the scheduler **600**. Each node computer **800** may provide the scheduler **600** and/or the service manager **700** with an availability status. A launcher **880** may reside on each node computer **800**. On command from the scheduler **600**, the launcher **880** can launch workers **155-1** to **155**-N on the node computer **800** to invoke computations using the node computer **800** (i.e., provide inputs to the worker **155** and receive outputs from the worker). The launcher **880** may also provide a worker **155** with access to infrastructure components of the compute backbone **300**, such as global cache **900**, and to the attendant operability of the compute backbone **300**, such as the ability to distribute computations (as discussed below in section E.). In the embodiment shown in **FIG. 2**, compute-dense valuation requests are performed on a pool of physically centralized node computers **800-1** to **800**-N located remotely from the local computers **100-1** to **100**-N. The node computers **800-1** to **800**-N need not be identical. In one embodiment, a node computer **800-1** may be, e.g. a Netra st A1000/D1000 made by Sun Microsystems, while another may be, e.g. a cluster of ProLiant BL e-class servers in a rack system made by Compaq.

[0088] **FIG. 7** is a block diagram illustrating certain components of a node computer **800** according to one embodiment of the present invention. As **FIG. 7** shows, at least one type of node computer **800** is a server having one or more central processing units (CPU) **820-1** to **820**-N in communication with a number of components by a shared data bus or by dedicated connections—these components include data storage devices **810**, one or more input devices **830** (e.g., CD-ROM drive and/or tape drive) which enable information and instructions to be input for storage in the node computer **800**, one or more output devices **840**, input/output (I/O) communications ports **850**, and software **860**. Each I/O communications port **850** has multiple communications channels for simultaneous connections with the node queue **550**, intermediate cache **1050** and global cache **900**. The software **860** may include an operating system **870**, a launcher **880** and other programs to manage information and perform the operations or transactions described herein. A node computer **800** of one such embodiment may be include one or more relatively high-speed CPUs **820-1** to **820**-N, and a relatively large amount of RAM. However, certain individual node computers **800-1** to **800**-N may have different physical qualities than others. For example, part of the compute backbone **300** may be a dedicated cluster. Some or all of the node computers **800-1** to **800**-N of one embodiment may be commodity computing devices, such as relatively inexpensive, standard items generally available for purchase such that they may be replaced easily as technology advancement provides faster and more powerful processors and larger more efficient data storage devices.

[0089] In one embodiment, the compute backbone **300** infrastructure may have heterogeneous node computers **800-1** to **800**-N the computing resources of which may be made available to a number of local computers **100-1** to **100**-N running different types of operating systems and completely independent applications **180-1** to **180**-N. For example, a local computer **100** running an operating system by Sun Microsystems may be capable of accessing a worker **155** that is written as a MicroSoft Windows dynamic link library (DLL).

[0090] vi. Global Cache **900**

[0091] Because the compute backbone **300** infrastructure of the embodiment shown in **FIG. 2** comprises a closely coupled cluster of resources with relatively fast interconnections between them, it is possible to give each node computer **800-1** to **800**-N access to a sufficiently low latency resource, in which to store its intermediate computation results. The global cache **900** of one embodiment is a persistent storage facility provided to the computations being executed on the compute backbone **300** which allows those computations to share intermediate data and/or to optimize database access. In one embodiment, a global cache **900** may include both a hardware configuration and a software component, the software component being configured such that the functionality of the global cache **900** will appear to be the same (and operate in the same manner) regardless of which particular hardware component or configuration is being used to implement the cache at a particular time. In one embodiment, a hardware configuration for the global cache **900** may include a number of components, some of which may be located in geographically separate locations.

[**0092**] Workers **155** running on the compute backbone **300** may use the global cache **900** to persist all intermediate data for which the time required to obtain such data (via either computation or accessing a database external to the compute backbone **300**) is at least marginally greater than the time it takes to persist it in the global cache **900**. For example, if it takes 50 ms to retrieve a 1 MB file and 50 ms to de-persist that file from global cache **900**, but it takes two seconds of computation time to compute the data stored in the 1 MB file, it may be more efficient to access the global cache **900** to obtain the file rather than computing the results contained in the file. The global cache **900** of one embodiment (i) provides workers **155-1** to **155**-N a place to store and retrieve intermediate computation results in a persistent storage, (ii) allows computations to share intermediate data that takes less time to persist than to re-compute or re-retrieve from an external source, and (iii) provides a means of inter-process communication between the workers **155-1** to **155**-N working on compute requests belonging to the same job **182**. In accordance with one embodiment, data stored in the global cache **900** is only visible to computations belonging to the same job **182**. In accordance with another embodiment, data stored in the global cache **900** is visible to computations of multiple jobs **182-1** to **182**-N.

[**0093**] The global cache **900** shown in **FIG. 2** is implemented as a file system on a storage area network (SAN) or a network attached storage (NAS) with a data rate of, for example, approximately 100-250 MB per second. However, in an alternative embodiment, the global cache **900** may also be implemented as a database running on a redundant array of independent disks (RAID) using a 1 gigabit ethernet

[**0094**] vii. Administrative General User Interface **1000**

[**0095**] The administrative general user interface (GUI) **1000** of one embodiment may allow administration of various aspects of the compute backbone **300** infrastructure and calling applications **180-1** to **180**-N running thereon, including (i) monitoring the operational availability of components of the compute backbone **300**, (ii) creating a new service and allocating resources to it, (iii) granting calling applications **180-1** to **180**-N rights to the allocated resources, and (iv) troubleshooting a service in the event of a failure. In particular, such an administrative GUI **1000** may enable a user **20** to deploy worker modules **195-1** to **195**-N and other data files to a service, and to upload and delete worker modules **195-1** to **195**-N. For example, using the administrative GUI **1000**, a user **20** can obtain accounting, usage and demand pattern information regarding computing and storage resources on the compute backbone **300**. Periodic reports can be generated to show a user **20** the amount of resources it requested, was allocated, and utilized for each calling application **180** run on the compute backbone **300**. Using the administrative GUI **1000**, a user **20** may also add, reserve or remove resources used by a service, such as node computers **800-1** to **800**-N and data storage.

[**0096**] The administrative GUI **1000** of one embodiment may also enable a user **20** to monitor the status of jobs **182-1** to **182**-N deployed and/or running on the node computers **800-1** to **800**-N, including the progress of each job **182** and its resource utilization. Logs generated by the workers **155-1** to **155**-N running in a particular job **182** may also be displayed on an administrative GUI **1000**. Furthermore, an authenticated user **20** may be able to cancel or suspend a job **182** through the administrative GUI **1000**, as well as change the priority of jobs **182-1** to **182**-N already scheduled for or undergoing computation on the compute backbone **300**. A user **20** may also cancel or reset an entire service using the administrative GUI **1000** of one embodiment, thereby terminating all jobs **182-1** to **182**-N running on the service.

[**0097**] In one embodiment, the administrative GUI **1000** is a personal computer capable of accessing the service manager **700** over a network connection such as local area network or an Internet.

II. Method Embodiments of the Invention

[**0098**] Having described the structure and functional implementation of certain aspects of embodiments of the system **10** of one embodiment, the operation and use of certain embodiments of the system **10** will now be described with reference to **FIGS. 6-11**, and continuing reference to **FIGS. 2-5**.

[**0099**] A. Method of Developing A Worker Module **195**

[**0100**] In one embodiment, an application developer **30** may create a worker module **195** to be a shared library capable of exposing its main compute function or engine, called a worker **155**, in accordance with a convention specified by an API **190**. In particular, the workers **155-1** to **155**-N within a particular worker module **195** may be uniquely identified by a name/version pair coded into the worker module **195** at the time it is compiled, and may be discovered by the compute backbone **300** during deployment of the worker module **195**. In one embodiment, a single worker module **195** may be configured to expose more than one worker **155-1** to **155**-N, perhaps simplifying somewhat the development and subsequent deployment of the worker module **195**. In some cases, a user **20** may be able to combine all of the functionality corresponding to a particular calling application **180** to be deployed on the compute backbone **300** into a single worker module.

[**0101**] B. Method of Deploying a Worker Module **195** on the Compute Backbone **300**

[**0102**] Rather than a traditional executable file, one embodiment of a worker module **195** deployed on the compute backbone **300** of one embodiment may be a shared library identified by its name, a session enterprise Java bean (EJB) or an executable file compliant with a compute backbone **300**. Once such a worker module **195** is developed, a user **20** and/or applications developer **30** may access the administrative GUI **1000** to deploy the worker module **195** onto the compute backbone **300**. Alternatively, a worker module **195** may be deployed programmatically. According to one embodiment, the compute backbone **300** checks to ensure that each worker **155** contained within a worker module **195** is unique before such a worker **155** may be deployed.

[**0103**] In such an embodiment, when a node computer **800** on the compute backbone **300** receives a job **182** with, for example, a particular computation to be performed, the node computer **800** may first initialize the worker module **195**, and then invoke one or more workers **155-1** to **155**-N embedded therein. This worker module **195** may then remain initialized, ready, for example, to perform further computations and/or to store intermediate data directly in global cache **900**. Such a worker module **195** need not, however, stay initialized for the duration of an entire job **182**. In certain instances, the compute backbone **300** infrastructure may have an need to reassign the node computer **800**, in which case the worker module **195** may be terminated, potentially causing any task **186** currently running on that node computer **800** to be rescheduled. In the event that a job **182** is rescheduled, however, the persistent global cache **900** may be available to provide intermediate results computed by the node computer **800** on which the job **182** was originally running, and to thereby allow the job **182** to continue computations using those intermediate results without being re-run in its entirety.

[**0104**] Using an administrative GUI **1000**, a user **20** and/or applications developer **30** may also deploy and manage additional data required by a worker module **195**, such as dependent shared libraries or configuration files. In one embodiment, any such extra data is to be stored in a directory accessible to the worker module **195** during runtime, and its location is made available to the computation as it is being processed.

[**0105**] One embodiment of the compute backbone **300** may be capable of detecting conflicts between worker modules **195**, and alerting users **20-1** to **20**-N in order to prevent deployment of worker modules **195** that export duplicate workers **155**. To help ensure service coherency, worker modules **195-1** to **195**-N deployed on the compute backbone **300** are to be unique. According to one embodiment, the service manager **700** may verify that not only the name and version number of a particular worker module **195** to be deployed is unique, but also that the functionality of a worker module **195** to be deployed has not already been deployed on the compute backbone **300**.

[**0106**] D. Method of Performing Computations Using a System with a Compute Backbone **300**

[**0107**] Rather than a number of users **20-1** to **20**-N each porting an entire long running executable computer program to run on a common platform of processors, one method embodiment of the present invention allows a user **20** to move just the compute-dense sections of a calling application **180** onto a network-accessible computing service, which is the compute backbone **300** described above.

[**0108**] According to one method embodiment of the present invention, certain computations may be accomplished by invoking a compute function (i.e., worker **155**) to access at least one input object (i.e., task input **187**) in order to create at least one output object (i.e., task output **189**). Inputs and outputs may both be objects in a particular programming language.

[**0109**] In this method embodiment, computations performed on the compute backbone **300** may be grouped in sets called jobs **182**. The jobs **182** of such an embodiment are to be the smallest units that can be managed either by a user **20** directly (through the administrative GUI **1000**) or programmatically. These jobs **182** may have meta-information associated with them (e.g., priority and specific resource requirements), which enable the service manager **700** to assign the job **182** to an appropriate node computer **800** at an appropriate time. According to this method embodiment, when creating a job **182**, a user **20** and/or application developer **30** specifies the worker **155** that will perform computations for a particular job **182**.

[**0110**] Once a job **182** is created, a calling application **180** may proceed to schedule computations, with the compute backbone **300**, in units called tasks **186**. According to one embodiment, a task **186** includes a task input **187** (e.g., an object or structured message) that is accessed by the worker **155** to create a task output **189** (e.g., another object or structured message). The task output **189** may be returned upon successful completion of the computation. In the case of a failure (i.e., the computation was not completed) an error indication may be returned in place of the task output **189**. The user **20** and/or application developer **30** may also specify optional global data to be used by the job **182** at the time the job **182** is created. This global data indicates to the scheduler **600** that it is to be made available to all computations within a job **182**.

[**0111**] In accordance with this method embodiment, the calling application **180** may indicate to the compute backbone **300** (in particular, the scheduler **600**) that its tasks **1861** to **186**-N are to be computed either synchronously or asynchronously. In a synchronous computation mode, a thread in a calling application **180** may first submit to the compute backbone **300** a job **182** containing one or more task **186-1** to **186**-N, and then wait for the results of each successive computation. In an asynchronous computation mode, a calling application **180** may submit the tasks **186-1** to **186**-N to the compute backbone **300** and receive back an identifier, unique in the scope of the particular job **182**, which the calling application **180** or some other application may later use to poll the compute backbone **300** for results (in particular, the transaction manager **400** and the queue **500**).

[**0112**] In one embodiment, the compute backbone **300** persistently stores in the queue **500** all task inputs **187-1** to **187**-N and task outputs **189-1** to **189**-N involved with a particular job **182**. In such an embodiment, this information may be deleted only when the job **182** is completed, or when the job **182** expires. According to this embodiment, however, the information is not to be deleted if the job **182** is terminated due to the failure or reassignment of the node computer **800** on which it was running. The time of expiration for a job **182** may be specified at the time the job **182** is created, and may be stored as part of the meta-information for use by the compute backbone (in particular, the scheduler **600** and/or service manager **700**).

[**0113**] **FIGS. 8***a***-8***b* illustrate certain operations performed in one embodiment of a method of computing a result using a system **10** as described above. In particular, a worker **155** is deployed on the compute backbone **300**. From another point of view, the compute backbone **300** obtains a worker module **195** which contains a worker **155** (step **1610**). Then, the compute backbone **300** obtains one or more jobs **182-1** to **182**-N associated with one or more calling applications **180-1** to **180**-N residing on one or more local computers **100-1** to **100**-N (step **1620**). Each job **182-1** to **182**-N is stored in the queue **500** prior to processing (step **1625**). The compute backbone **300** determines availability of the node computers **800-1** to **800**-N (step **1630**), and schedules the jobs **182-1** to **182**-N on available node computers **800-1** to **800**-N in accordance with any specification of a minimum number or type of nodes necessary for the job as specified by meta-information (step **1640**). The jobs **182-1** to **182**-N are then sent to the proper node computers **800-1** to **800**-N and initiated or opened on those nodes (step **1650**). When a node computer **800** receives a job **182**, the node computer **800** determines whether or not the worker module **195** containing the worker **155** to be called has been loaded into the memory **820** of the node computer **800** (step **1660**). If the worker module **195** containing the compute function to be invoked by the job **182** has not yet been loaded, the node computer **800** accesses the worker module **195** and loads it into the memory **820** of the node computer **800** (step **1670**). In one embodiment, the job **182** may then receive one or more tasks **186-1** to **186**-N and, if provided, global data. According to the job **182** of a particular calling application **180**, the node computer **800** then calls the worker **155** to get a result (step **1680**). Although the job **182** need not receive a task **186** at the time of job creation, a task **186** may be supplied at that time. Once the compute function has accessed the task input **187** to create the task output **189**, the node computer **800** makes the task output **189** available on the compute backbone **300** (in particular, the queue **500** and/or transaction manager **400**) such that the calling application **180** is able to retrieve the result (step **1680**).

[**0114**] While a job **182** being processed on the compute backbone, access to the job **182** need not be limited only to the particular calling application **180** that initiated it. In one method embodiment, once a job **182** is created, other processes may be attached to the job **182** and have access to the same functionality as the original job **182**. According to one method embodiment, two or more calling applications **180** may access a particular job **182**. For example, the calling application **180-1** of one service may be sending information to a job **182** while the calling application **180-2** of a second service is receiving information from the job **182**. In such an embodiment, the user **20** of the calling application **180-2** of the second service need not know where the inputs to the job **182** originated, what those inputs contain, or where the job **182** is being processed on the compute backbone **300**.

[**0115**] In a particular method embodiment, a job **182** is given an identifier at the time it is created such that the job **182** may be uniquely identified by the compute backbone **300**. A first calling application **180-1** then sends the job **182** to the compute backbone **300** for processing. During such processing, a second calling application **180-2** may request access to the job **182**. If the user **20** of the second calling application **180-2** has appropriate access (e.g., confirmed by entry of a password assigned to the user **20** of the second calling application **180-2**), the second calling application **180-2** may be granted access to the job **182**.

[**0116**] E. Method of Dividing Computations

[**0117**] The system **10** according to one embodiment of the present invention may also enable computations to be distributed and to support certain patterns of communication and job logic. For example, a job **182** running on a node computer **800** of the compute backbone **300** may itself create a new "descendant" job, which creates its own task inputs **187-1** to **187**-N and retrieve its own task outputs **189-1** to **189**-N. Those descendent jobs **182-1** to **182**-N created by the "parent" job **182** are new jobs themselves, and may then be scheduled by the scheduler **600** and may be sent for computation, for example, to different node computers **800-1** to **800**-N, and to a node computer **800** other than the one processing the parent job **182**. Upon completion of the descendant jobs **182-1** to **182**-N, the parent job **182** may aggregate the results of the descendant jobs **182-1** to **182**-N and use them as task inputs **187-1** to **187**-N to in turn create task output **189** for the parent job **182**.

[**0118**] **FIG. 9** illustrates certain operations performed in one embodiment of a method of computing a result using jobs that recursively divide. In particular, a parent job **182** may be scheduled and sent to a node computer **800** by the scheduler **600** (step **1710**). The parent job **182** may be received by the compute backbone **300** from a calling application **180**, or may itself be a descendant job. Such a parent job **182** may be programmed to include meta-information such that the node computer **800** will (1) divide out any descendant jobs **182-1** to **182**-N, each of which then may be sent to the scheduler **600** (step **1720**), and (2) identify the job as a parent job. Using the meta-information associated with each descendant job **182-1** to **182**-N, the scheduler **600** may prioritize and send those descendants to available node computers **800-1** to **800**-N for computation (step **1730**). In such an embodiment, the scheduler **600** may avoid reassigning the node computer **800** on which a parent job **182** is running (and may avoid otherwise terminating the parent job **182**) until all descendant jobs **182-1** to **182**-N have been completed. In this way, although the node computers **800** may be considered volatile resources for purposes of processing jobs in general (because a node computer running a job other than a parent job **182** may be re-assigned by the scheduler **600** at any time, and the scheduler **600** may re-assign a non-parent job to a new node computer **800** at any time), a node computer processing a parent job **182** is given priority over other node computers until all of its descendant jobs **182-1** to **182**-N have completed.

[**0119**] The node computer **800** may process the descendant job according to one or more workers **155-1** to **155**-N specified by meta-information contained in the descendant job (step **1740**). Upon completion of each descendant job **182-1** to **182**-N, each node computer **800-1** to **800**-N running a descendant job **182** may make the result from each such job available to the parent job **182** by storing those results in the queue **500** (step **1750**). In addition, intermediate and/or final results of each descendant job may be stored in the global cache **900** for use by other jobs, including other descendant jobs and/or the parent job (step **1760**). Then, the parent job **182** may access the queue **500** and/or global cache **900** to obtain the results from the descendant jobs **182-1** to **182**-N, which may be task outputs **189-1** to **189**-N of the descendant jobs **182-1** to **182**-N, and may use them to create its own result (another task output

189) (step **1770**). As a further example, the results from the descendant jobs **182-1** to **182**-N may be sent directly to the parent job **182** without passing through the queue **500** and/or global cache **900**. The result created by the parent job **182** then may be sent from the node computer **800** to the transaction manager **400** for retrieval by the calling application **180** (step **1780**).

[**0120**] In one embodiment, the scheduler **600** may contain algorithms which recognize meta-information in a parent job **182** that identifies it as such, and may attempt to ensure that the node computer **800** on which a parent job **182** is running is not interrupted until all of the descendant jobs **182-1** to **182**-N have been completed. Furthermore, such meta-information may identify a particular worker **155** for use in performing a computation. If the scheduler **600** must vacate a node computer **800**, the scheduler **600** of such an embodiment will endeavor not to vacate a node computer **800** that has parent jobs **182-1** to **182**-N running on it. However, if a parent job **182** is prematurely terminated (step **1752**), all of its descendants may also be terminated (step **1754**).

[**0121**] F. Method of Caching Results

[**0122**] In one embodiment, all processes running on the node computers **800-1** to **800**-N of the compute backbone **300** have access to the global cache **900**. During computation of a particular job **182** on a particular node computer **800**, intermediate or partial results created by the job **182** may be stored in the global cache **900**. For example, a worker module **195** may store an intermediate result as it computes a task **186**. In addition, a job **182** may store in the global cache **900** data obtained from sources external to the node computers **800-1** to **800**-N. According to this embodiment, once the intermediate result or other external data is stored in the global cache **900**, all jobs **182-1** to **182**-N within the proper scope that are running on all node computers **800-1** to **800**-N of the compute backbone **300** have access to it. The scopes may include (1) a service-level scope, wherein the cached result is made available to all jobs **182-1** to **182**-N within a particular service, (2) a parent-level scope, wherein the cached result is made available to the parent job and all of its descendant jobs, and (3) a job-level scope, wherein the cached result is made available only to tasks **186-1** to **186**-N within one particular job **182**.

[**0123**] The global cache **900** of one embodiment may have an interface similar to a hash map. This global cache **900** may access data using a key/result pair, each key being unique within the scope of a job **182**.

[**0124**] At the time a job **182** is created, a user **20** and/or applications developer **30** may identify intermediate or partial results of a job **182** that might be cached in the global cache **900** more quickly than they could be computed by a particular node computer **800** or retrieved from a source external to the compute backbone **300**. For example, a high speed network connection may allow a node computer **800** to access previously computed data stored in the global cache **900** more quickly than the node computer **800** can itself compute the cached data. Also at the time a job **182** is created, a user **20** and/or application developer **30** may identify data from sources external to the global cache **900** that might be cached by a job **182** to reduce contention by other node computers **800** or other components of the compute backbone **300** for the external resource.

[**0125**] **FIGS. 10***a* and **10***b* illustrate certain operations performed in one embodiment of a method of caching intermediate results. In particular, a calling application **180** may send a job **182** identifying a worker **155** by its name/version pair to the compute backbone **300** (step **1810**). The scheduler **600** may then send the job **182** to an available node computer **800** (step **1815**). The node computer **800** may then process the job **182** and create a result previously identified as a partial or intermediate result to be made available to other computations (step **1820**). The node computer **800** then may send the partial or intermediate result to the global cache **900** for storage therein (step **1825**). In accordance with one embodiment, a key/result pair may be assigned to the stored intermediate result. If a job **182** terminates during computation (e.g., by reassignment of the node computer to a new service (step **1830**) or by failure of the node computer **800**), the scheduler **600** may send the job **182** to another available node computer **800-2** (step **1835**). The new node computer **800-2** then may access the global cache **900** to retrieve intermediate data computed during the initial processing of the job such that the job need not be recomputed in its entirety (step **1840**). At some later time, any job **182-2** running on any node computer **800** can access the global cache **900** to retrieve the partial or intermediate result from the earlier job **182-1**, which may have been computed on a different node computer **800** and may have terminated long ago (step **1845**).

[**0126**] According to the method embodiment shown in **FIGS. 10***a*-**10***b*, a job **182-2** seeking to retrieve a cached result from an earlier job **182-1** may present to the global cache **900** a lookup function which is atomic because it has both a key and a compute function associated with the result sought to be retrieved from the global cache **900**. In the event that the key is found (step **1855**), the global cache **900** returns the requested result to the job **182-2**. If the key is not found (step **1860**), however, the node computer **800** on which the job **182-2** is running may compute the requested result using the compute function of the lookup function. In the event that a subsequent job **182-3** attempts to access the result currently being computed, the node computer **800** on which that subsequent job **182-3** is being run may be prevented from computing the compute function and, instead, prompted to wait for the job **182-2** computing the result to finish its computation and caching of the result (step **1865**). In this embodiment, the job **182** may seek the result of a function that has been identified as cachable, so that the key and associated compute function are presented to the cache, hence the global cache **900** access is atomic from the viewpoint of the worker module.

[**0127**] In accordance with one embodiment, calling one atomic lookup function may return several intermediate results at once. In such an embodiment, the lookup function includes a key and a compute function for each of the intermediate results called for by the lookup function.

[**0128**] G. Illustrative Computation According to Method Embodiments

[**0129**] To further illustrate both a method of caching intermediate results and a method of computing a result using recursively dividing jobs **182-1** to **182**-N, consider a calling application **180** programmed to compute the value of a portfolio containing one thousand instruments. Consider also that the calling application **180** is programmed to reflect the market environment in which the value of the particular portfolio is to be determined. Further consider that at least a portion of the market environment must also be established (e.g., certain yield curves must be computed in order to fully define the market environment).

[0130] According to one method embodiment, the calling application **180** may invoke a worker **155** called "value portfolio," and also pass to the compute backbone **300** a set of inputs representing the market environment in which the value of the particular portfolio is to be calculated. Next, the "value portfolio" worker **155** may perform some preliminary yield curve calculations to more fully define the market environment. The results of those preliminary calculations may be stored in the global cache **900** and made available to other "value portfolio" workers **155-1** to **155**-N. Such intermediate results defining the market environment (now stored in global cache **900**) may be available to the "value portfolio" worker **155** as well as all other jobs **182-1** to **182**-N running on all other node computers **800-1** to **800**-N within a particular service. Then, according to the "value portfolio" worker **155**, one thousand separate descendant jobs **182-1** to **182-1000** named, for example, "value instrument no. 1,""value instrument no. 2," etc., are divided out and sent to the scheduler **600** for assignment to an available node computer **800** within the service. The one thousand descendant jobs **182-1** to **182-1000** may each be sent to and processed on available node computers **800-1** to **800**-N. During processing, each of the descendant jobs **182-1** to **182-1000** has access to the market environment results computed earlier and stored in the global cache **900**. As a result, the descendant jobs **182-1** to **182-1000** may not need to perform the yield curve computation themselves and may not need to contact the calling application **180** for such information, but rather, can more quickly obtain the results of the yield curve computation stored in the global cache **900**. Upon completion of each of the one thousand descendant jobs **182-1** to **182-1000**, the "value portfolio" job **182** aggregates the outputs from the "value instrument" jobs **182-1** to **182-1000** for further computation of a portfolio value result.

[0131] H. Method of Troubleshooting/Debugging One Embodiment of a System

[0132] One embodiment of the system **10** also has additional functionality that may allow a worker **155** to be deployed on a local computer **100** without accessing the compute backbone **300** infrastructure or the network **200**. To allow an applications developer **30** to debug its worker modules **195-1** to **195**-N locally on its local computer **100** (which, in one embodiment, is the development host for the applications developer **30**), the compute backbone **300** is capable of (i) providing a simplified replica of itself, including an API **190**, and (ii) initializing worker modules **195-1** to **195**-N in the same process space in which the calling application **180** resides. Such a capability may enable an applications developer **30** to debug functionality, such as persistence and parameter passing, in an environment where the developer **30** has access to all necessary information about both the calling application **180** and the environment on which it is running (i.e., the replicated functionality of the compute backbone **300**). For example, if a worker module **195** performs properly on the local computer **100**, it will also perform properly when deployed on the compute backbone **300**.

[0133] **FIG. 11** illustrates certain operations performed in one embodiment of a method of running a calling application **180** in local mode. For any particular calling application **180**, an applications developer **30** may create both a worker module **195** and one or more jobs **182** (step **1910**). At initialization, the developer **30** links the calling application **180** to the API **190** file associated with local mode operation (as opposed to the API **190** file associated with network mode operation) (step **1920**). The API **190** then loads the worker module **195** into the process space of the local computer **100** (step **1930**). The API **190** ensures that a replica of all major functions performed by the compute backbone **300** (e.g., scheduling, caching, etc.) are loaded into the data storage devices **110-1** to **110**N of the local computer **100** (step **1940**). The worker **155** is then processed on the CPU **120** of the local computer **100** (step **1950**). Unlike the parallel computing operation of network mode on the actual compute backbone **300** infrastructure, processing in local mode is accomplished sequentially, or perhaps concurrently if multithreading is used.

[0134] Although illustrative embodiments and example methods have been shown and described herein in detail, it should be noted and will be appreciated by those skilled in the art that there may be numerous variations and other embodiments which may be equivalent to those explicitly shown and described. For example, the scope of the present invention is not necessarily limited in all cases to execution of the aforementioned steps in the order discussed. Unless otherwise specifically stated, the terms and expressions have been used herein as terms and expressions of description, not of limitation. Accordingly, the invention is not limited by the specific illustrated and described embodiments and examples (or the terms or expressions used to describe them) but only by the scope of appended claims.

1. A method, comprising:

receiving, for computation by a node computing device of a distributed computing system, a parent job configured to produce one or more descendant jobs, wherein said node computing device is one of a plurality of node computing devices of said distributed computing system;

scheduling computation of said parent job on said node computing device, said distributed computing system further comprising a scheduler server configured to selectively reschedule computation of a job other than said parent job from any one of said plurality of node computing devices to another of said node computing devices; and

preventing rescheduling of said parent job unless each of said descendant jobs is completed or terminated.

2. (canceled)

3. The method of claim 1, said distributed computing system further comprising a persistent data storage queue in communication with said node computing device, wherein a minimum availability of said distributed computing system is defined by an availability of said persistent data storage; and

wherein said method further comprises:

storing a descendant output from each of said descendant jobs in said persistent queue for retrieval by said node computing device processing said parent job; and accessing said persistent queue to retrieve said descendant output for use in computation of said parent job.

4. The method of claim 1, wherein none of said node computing devices is available for computation at a time when said parent job is scheduled for computation.

5. The method of claim 1, further comprising sending for computation each descendant job to a node computing device other than said node computing device processing said parent job.

6. The method of claim 1, wherein said parent job comprises meta-information comprising an instruction to divide one or more of said descendant jobs from said parent job for scheduling by said scheduler server and processing by at least one of said node computing devices.

7. The method of claim 1, further comprising terminating each of said descendant jobs upon termination of said parent job.

8. The method of claim 1, wherein each of said node computing devices provides to said scheduler server an availability status.

9. The method of claim 1, further comprising receiving said parent job from an application running on a local computing device.

10. The method of claim 9, further comprising providing an output of said parent job for retrieval by said application.

11. The method of claim 1, further comprising storing a descendant output from at least one of said descendant jobs in a cache for use by another of said descendant jobs or said parent job.

12. The method of claim 1, wherein said descendant job comprises meta-information comprising an identification of a compute function to be used to perform a computation for said descendant job.

13. A distributed computing system, comprising:

a plurality of node computing devices;

means for receiving, for computation by at least one of said node computing devices, a parent job configured to produce one or more descendant jobs;

means for scheduling computation of said parent job on said node computing device, said means for scheduling further configured to selectively reschedule computation of a job other than said parent job from any one of said plurality of node computing devices to another of said node computing devices; and

means for preventing rescheduling of said parent job unless each of said descendant jobs is completed or terminated.

14. (canceled)

15. The distributed computing system of claim 13, further comprising:

a persistent data storage queue in communication with said node computing devices, wherein a minimum availability of said distributed computing system is defined by an availability of said persistent data storage;

means for storing a descendant output from each of said descendant jobs in said persistent queue for retrieval by said node computing device processing said parent job; and

means for accessing said persistent queue to retrieve said descendant output for use in computation of said parent job.

16. The distributed computing system of claim 13, wherein none of said node computing devices is available for computation at a time when said parent job is scheduled for computation.

17. The distributed computing system of claim 13, further comprising means for sending for computation each descendant job to a node computing device other than said node computing device processing said parent job.

18. The distributed computing system of claim 13, wherein said parent job comprises meta-information comprising an instruction to divide one or more of said descendant jobs from said parent job for scheduling by said means for scheduling and processing by at least one of said node computing devices.

19. The distributed computing system of claim 13, further comprising means for terminating each of said descendant jobs upon termination of said parent job.

20. The distributed computing system of claim 13, wherein each of said node computing devices provides to said means for scheduling an availability status.

21. The distributed computing system of claim 13, further comprising means for receiving said parent job from an application running on a local computing device.

22. The distributed computing system of claim 21, further comprising means for providing an output of said parent job for retrieval by said application.

23. The distributed computing system of claim 13, further comprising a cache configured to store a descendant output from at least one of said descendant jobs for use by another of said descendant jobs or said parent job.

24. The distributed computing system of claim 13, wherein said descendant job comprises meta-information comprising an identification of a compute function to be used to perform a computation for said descendant job.

25. A method, comprising:

receiving, for computation by a node computing device of a distributed computing system, a parent job configured to produce a descendant job, wherein said node computing device is one of a plurality of node computing devices of said distributed computing system and said distributed computing system further comprises a scheduler server configured to selectively reschedule computation of one or more jobs from any of said plurality of node computing devices to another one or more of said node computing devices;

using said distributed computing system to create said descendant job of said parent job;

scheduling computation of said parent job on said node computing device; and

scheduling computation of said descendant job on another of said plurality of node computing devices.

26. The method of claim 25, wherein said parent job comprises data descriptive of an indication informing said scheduler server that said parent job is not to be rescheduled unless said descendant job is completed.

27. The method of claim 25, said distributed computing system further comprising a persistent data storage queue in communication with said node computing device, wherein a minimum availability of said distributed computing system is defined by an availability of said persistent data storage; and

wherein said method further comprises:

storing a descendant output from said descendant job in said persistent queue for retrieval by said node computing device processing said parent job; and

accessing said persistent queue to retrieve said descendant output for use in computation of said parent job.

28. The method of claim 25, wherein said parent job comprises meta-information comprising an instruction to divide said descendant job from said parent job for scheduling by said scheduler server and processing by at least one of said node computing devices.

29. The method of claim 25, further comprising terminating said descendant job upon termination of said parent job.

30. The method of claim 25, wherein each of said node computing devices provides to said scheduler server an availability status.

31. The method of claim 25, further comprising receiving said parent job from an application running on a local computing device.

32. The method of claim 31, further comprising providing an output of said parent job for retrieval by said application.

33. The method of claim 25, further comprising storing a descendant output from said descendant job in a cache for use by another descendant job or said parent job.

34. The method of claim 25, wherein said descendant job comprises meta-information comprising an identification of a compute function to be used to perform a computation for said descendant job.

35. A distributed computing system, comprising:

a plurality of node computing devices;

means for receiving, for computation by one of said node computing devices, a parent job configured to produce a descendant job;

means for creating said descendant job of said parent job; and

a scheduler server configured to:

selectively reschedule computation of one or more jobs from any of said plurality of node computing devices to another one or more of said node computing devices;

schedule computation of said parent job on said node computing device; and

schedule computation of said descendant job on another of said plurality of node computing devices.

36. The distributed computing system of claim 35, wherein said parent job comprises data descriptive of an indication informing said scheduler server that said parent job is not to be rescheduled unless said descendant job is completed.

37. The distributed computing system of claim 35, further comprising:

a persistent data storage queue in communication with said node computing device, wherein a minimum availability of said distributed computing system is defined by an availability of said persistent data storage;

means for storing a descendant output from said descendant job in said persistent queue for retrieval by said node computing device processing said parent job; and

means for accessing said persistent queue to retrieve said descendant output for use in computation of said parent job.

38. The distributed computing system of claim 35, wherein said parent job comprises meta-information comprising an instruction to divide said descendant job from said parent job for scheduling by said scheduler server and processing by at least one of said node computing devices.

39. The distributed computing system of claim 35, further comprising means for terminating said descendant job upon termination of said parent job.

40. The distributed computing system of claim 35, wherein each of said node computing devices provides to said scheduler server an availability status.

41. The distributed computing system of claim 35, further comprising means for receiving said parent job from an application running on a local computing device.

42. The distributed computing system of claim 41, further comprising means for providing an output of said parent job for retrieval by said application.

43. The distributed computing system of claim 35, further comprising a cache configured to store a descendant output from said descendant job in a cache for use by another descendant job or said parent job.

44. The distributed computing system of claim 35, wherein said descendant job comprises meta-information comprising an identification of a compute function to be used to perform a computation for said descendant job.

45. The method of claim 1, wherein said parent job comprises meta-information indicating that a specific resource is required for computation of said parent job.

46. The distributed computing system of claim 13, wherein said parent job comprises meta-information indicating that a specific resource is required for computation of said parent job.

47. The method of claim 25, wherein said parent job comprises meta-information indicating that a specific resource is required for computation of said parent job.

48. The distributed computing system of claim 35, wherein said parent job comprises meta-information indicating that a specific resource is required for computation of said parent job.

49. The method of claim 1, wherein said preventing rescheduling further comprises preventing termination or restarting of said parent job unless each of said descendant jobs is completed or terminated, but allowing suspension or stateful process migration of said parent job.

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