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### Hardware co-ordination of resource management in distributed systems

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#### Abstract

Systems and methods are directed to methods and apparatus for transferring ownership of common resources from a source entity, which owns a resource, to a destination entity, which will own the resource, in a distributed system. The method includes the source entity receiving a command to change ownership (the MOVE command), and then marking the source entity as no longer owning the common resource. The source entity then sends a MOVE command to the destination entity, which will then update its common resource ownership table to reflect that the ownership of the common resource has been transferred from the source entity to the destination entity. It is advantageous that the updating of ownership of the common resource in the source entity occur simultaneously with the dispatching of the MOVE command to the destination entity.

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## **Background/Summary**

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application is a divisional of U.S. patent application Ser. No. 16/298,419, entitled "Hardware Co-ordination of Resource Management in Distribution Systems," filed Mar. 11, 2019, and assigned to the assignee hereof, the contents of which are hereby incorporated by reference in their entirety.

### **FIELD OF DISCLOSURE**

(1) Disclosed aspects are directed to distributed electronic systems. More specifically, exemplary aspects are directed to sharing resources in distributed electronic systems.

### **BACKGROUND**

(2) As electronic and packaging fields advance more and more, functionality can be squeezed into distributed systems. Because of the large number of independent electronic entities that can be included in distributed systems, it is advantageous that entities share resources, for example, so that functional units are not duplicated needlessly. It is also advantageous that the sharing of resources be done efficiently, for example, so the latency caused by such sharing is reduced.

(3) Accordingly, there is a need for improved management of resource ownership in distributed systems.

### **SUMMARY**

(4) Exemplary aspects of the invention are directed to hardware, systems and methods for managing resources in distributed systems.

(5) In one embodiment a method for use in an exemplary distributed system, which includes a source entity and a destination entity, is disclosed. Each entity in the distributed system has a common resource ownership table that records ownership, i.e. which entity may access a common resource. The resources which are shared by various entities in the distributed system are the common resources as more than one entity may access them, but only one entity may access a common resource at a time. The common resource ownership table records which entities own, i.e. may access, the common resource. The entity that may access the common resource is said to own that resource and any accesses of the common resource are performed by the entity that owns the common resource.

(6) The method includes determining, by a source entity, that ownership of a common resource (the right to access a common resource) in a distributed system is to be transferred to a destination entity. The method further includes updating the common resource ownership table, of the source entity, to reflect that the source entity no longer owns the common resource; and then sending a MOVE command to another entity within the distributed system reflecting that the common resource ownership has been changed from the source entity to the destination entity.

(7) In another embodiment a method of controlling access to a common resource in an exemplary

distributed system is disclosed. The method includes generating, by a non-source entity (an entity that does not own the common resource), a request to access the common resource. The method further includes transmitting the access request to a source entity, generating an access of the common resource by the source entity; and directing a result of the access of the common resource to the non-source entity.

(8) In a further embodiment a method of transferring ownership of a common resource in an exemplary distributed system in which a source entity, which owns the common resource, is not known by an originating entity is disclosed. The originating entity which is the entity that generates the access request for access of a common resource), is requesting the transfer of ownership but is not the source entity. The method includes accepting of a MOVE command by a non-source originating entity having a common resource ownership table, examining, by the originating entity, of the common resource ownership table to determine which entity owns the common resource; and sending a MOVE command from the originating entity to the source entity indicating that the transfer of ownership of the common resource from the source entity to a destination entity is requested.

(9) In a further embodiment a method of transferring ownership of a common resource in an exemplary distributed system when a source entity, which owns the common resource, does not have a common resource ownership table, is disclosed. The method includes the accepting of a MOVE command by an entity not having a common resource ownership table, noting, by the entity not having a common resource ownership table, that it no longer owns the common resource, and sending a MOVE command from a non-source entity to at least one other entity indicating that the transfer of ownership of the common resource from the source entity to a destination entity is indicated.

(10) In a further embodiment a method of forwarding an access request and common resource ownership from a source entity to a destination entity in an exemplary distributed system is disclosed. The method includes receiving, at the destination entity, an indication that the ownership of a common resource is to be moved from the source entity to the destination entity; and examining a source entity command queue to determine if there is an access request of the common resource for the destination entity and a MOVE command transferring ownership of the common resource to the destination entity. If both the MOVE command and the access request are present insuring that the MOVE command reaches the destination entity prior to the access request reaching the destination entity.

(11) An apparatus for transferring common resource ownership in an exemplary distributed system is disclosed. The apparatus includes an input for receiving, by a source entity an indication that ownership of a common resource is to be transferred, a common resource ownership table for updating the ownership by the source entity to reflect that the source entity no longer owns the common resource, and circuitry for sending a MOVE command to another entity within the distributed system reflecting the change of the common resource ownership has been changed from the source entity to a destination entity.

(12) In a further embodiment an exemplary apparatus for controlling access to a common resource in a distributed system is disclosed. The apparatus includes circuitry configured to generate, by a non-source entity, a request to access the common resource, circuitry configured to transmit the access request to a source entity, circuitry configured to generate an access of the common resource by the source entity; and circuitry configured to directing a result of the access of the common resource to the non-source entity.

(13) In a further embodiment an apparatus for transferring ownership of a common resource in an exemplary distributed system when a source entity, which owns the common resource, is not known by an originating entity requesting the transfer of ownership is disclosed. The apparatus includes circuitry configured to accept a MOVE command by a non-source originating entity having a common resource ownership table, circuitry configured examining, by the non-source

entity, of the common resource ownership table to determine which entity owns the common resource; and circuitry configured to send a MOVE command from the non-source entity to the source entity indicating that the transfer of ownership of the common resource from the source entity to a destination entity.

(14) In a further embodiment an apparatus configured to transfer ownership of a common resource in an exemplary distributed system when the source entity, which owns the common resource, but does not have a common resource ownership table, is disclosed. The apparatus includes source entity circuitry configured to accept a MOVE command, an indicator as to whether the source entity owns the common resource or not, source circuitry configured to note whether the source entity owns the common resource or not; and circuitry configured to send a MOVE command from a non-source entity to at least one other entity indicating that the transfer of ownership of the common resource from the source entity to a destination entity has occurred.

(15) In a further embodiment an apparatus configured to forward an access request and common resource ownership from a source entity to a destination entity is disclosed. The apparatus includes circuitry configured to receive, at the destination entity, an indication that ownership of a common resource is to be moved from the source entity to the destination entity, a source entity command queue for storing commands for the source entity prior to executing them, and circuitry configured to examine the source entity command queue to determine if there is an access request of the common resource for the destination entity and a MOVE command transferring ownership of the common resource to the destination entity, and if both the MOVE command and the access are present, circuitry to ensure that the MOVE command reaches the destination entity prior to the access request reaching the destination entity.

(16) In a further embodiment an apparatus configured to transfer common resource ownership in an exemplary distributed system is disclosed. The apparatus includes means for receiving, by a source entity an indication that ownership of a common resource is to be transferred, means for updating the ownership by the source entity to reflect that the source entity no longer owns the common resource; and means for sending a MOVE command to another entity within the distributed system reflecting the change of the common resource ownership has been changed from the source entity to a destination entity.

(17) In a further embodiment a non-transitory computer-readable storage medium comprising code, which, when executed by a processor, causes the processor to perform operations for managing resource ownership in an exemplary distributed system, is disclosed. The code contained in the non-transitory computer-readable storage medium includes code for receiving, by a source entity an indication that ownership of a common resource is to be transferred, code for updating the ownership by the source entity to reflect that the source entity no longer owns the common resource, and code for sending a MOVE command to another entity within the distributed system reflecting the change of the common resource ownership has been changed from the source entity to a destination entity.

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## Description

### BRIEF DESCRIPTION OF THE DRAWINGS

(1) The accompanying drawings are presented to aid in the description of aspects of embodiments of the invention and are provided solely for illustration of the aspects and not limitation thereof.

(2) FIG. 1 is a graphic illustration of a simple exemplary distributed system.

(3) FIG. 2 is a graphical representation of a portion of an illustrative distributed system.

(4) FIG. 3 is a graphical illustration of a transfer of resource ownership between entities.

(5) FIG. 4 is a flow chart illustrating the transfer of resource ownership between entities.

(6) FIG. 5 is a graphical representation of a portion of an illustrative distributed system.

(7) FIG. 6 is a graphical representation of a portion of an illustrative distributed system.

#### DETAILED DESCRIPTION

(8) Aspects of the invention are disclosed in the following description and related drawings directed to specific aspects of the invention. Alternate aspects may be devised without departing from the scope of the invention. Additionally, well-known elements of embodiments of the invention will not be described in detail or will be omitted so as not to obscure the relevant explanatory details of the teachings herein.

(9) The word “exemplary” is used herein to mean “serving as an example, instance, or illustration.” Any aspect described herein as “exemplary” is not necessarily to be construed as preferred or advantageous over other aspects. Likewise, the term “aspects of the invention” does not require that all aspects of the invention include the discussed feature, advantage or mode of operation.

(10) The terminology used herein is for the purpose of describing particular aspects only and is not intended to be limiting of aspects of the invention. As used herein, the singular forms “a,” “an,” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises,” “comprising,” “includes,” and/or “including,” when used herein, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

(11) Further, many aspects are described in terms of sequences of actions to be performed by, for example, elements of a computing device. It will be recognized that various actions described herein can be performed by specific circuits (e.g., application specific integrated circuits (ASICs)), by program instructions being executed by one or more processors, or by a combination of both. Additionally, the sequence of actions described herein can be considered to be embodied entirely within any form of computer-readable storage medium having stored therein a corresponding set of computer instructions that upon execution would cause an associated processor to perform the functionality described herein. Thus, the various aspects of the invention may be embodied in a number of different forms, all of which have been contemplated to be within the scope of the claimed subject matter. In addition, for each of the aspects described herein, the corresponding form of any such aspects may be described herein as, for example, “logic configured to” perform the described action.

(12) For the purpose of this disclosure, a distributed system contains, but is not limited to, electronic entities (entities) that comprise, but are not limited to, an input for receiving information, an output for conveying information and a message-passing mechanism for communicating with other entities. The input for receiving information and the output for communicating with other entities, as well as the message-passing bus may actually be the same physical connection, for example, a serial or parallel bus serving as both an input and an output, but they need not be.

(13) For the purposes of this disclosure, a shared resource (resource) is defined as a shared device, e.g., a memory table, a floating point unit, an input/output unit, a register or the like, which is used by different entities at different times, for example, a shared resource may be accessed by different threads in a multi-threaded computing environment.

(14) For the purposes of this disclosure, an owner is defined as the singular, chosen access controller which serves as the gateway to a shared resource. Ownership (and non-ownership) may be contained within an entity in a common resource ownership table (though it need not be) so that the entity can know if it may access the shared resource. Once the shared resource is owned, the owner entity can access or grant access to the shared resource.

(15) For the purposes of this disclosure, an access is defined as any operation which requires communication, e.g. a write to or a read from a common resource.

(16) For the purposes of this disclosure, a MOVE command is a command that transfers ownership of a shared resource from one entity to another. The MOVE command includes an identification of a common resource and an identity of the entity to which the common resource ownership is to be

moved to, though it may contain other information as well.

(17) For the purposes of this disclosure, a source entity is an entity that owns a common resource.

(18) For the purposes of this disclosure, a destination entity is an entity that the ownership of a common resource will be transferred to.

(19) For the purposes of this disclosure, an origination entity is the non-source and non-destination entity in which a MOVE instruction may originate.

(20) For the purposes of this disclosure, a common resource ownership table (aka common resource table, common ownership table, and resource ownership table) is a listing of entities which entity currently owns a common resource.

(21) FIG. 1 is a graphic illustration of a simple exemplary distributed system. Generally, a distributed system is a system in which computing resources are decentralized into a plurality of entities which cooperate to function properly. Such cooperation is commonly accomplished by having a mechanism to pass messages between the entities. The system of FIG. 1 is an example of a simple distributed system. FIG. 1 shows element **101**, an exemplary portion of a distributed system, comprising various semiconductor dies, **103**, **109a**, **109b**, **109c**, **115a**, **115b** and **115c** on a carrier substrate **102**. In FIG. 1, three CPU (Central Processing Unit) dies, **115a**, **115b**, and **115c**, are coupled to three memory management unit dies, **109a**, **109b**, and **109c** by three interconnection buses **113a**, **113b** and **113c**, respectively. The three memory management units' dies **109a**, **109b**, and **109c** are further coupled to a memory die **103** via a memory bus **107**. Memory die **103** contains table **105** which the three CPU dies **115a**, **115b**, and **115c** will access. Since there is only one table **105**, the CPU dies **115a**, **115b**, and **115c** must take turns accessing the table **105**. Access to the table **105** is mediated over a message-passing bus **111**. Memory management unit dies **109a**, **109b**, and **109c** use the message-passing bus **111** to share ownership and transfer ownership of the table **105**. One way to control ownership (permission to read from or write to a common resource which may be used by a plurality of entities) is to maintain within each entity an ownership table which lists each entity and which entity owns the common resource and is therefore permitted to access that common resource. Herein such a table is referred to as a common resource ownership table. Only the owner of table **105**, the source entity, may access it at a given time, so access to the table **105** is managed using the message-passing bus **111**. Such message-passing "bus" may be a serial or parallel bus as illustrated by the message-passing bus **111**, or it may be a virtual channel of some sort. Any mechanism that can convey messages between entities is considered herein to be a message-passing "bus."

(22) When multiple entities, such as the memory management unit dies **109a**, **109b**, and **109c**, are reading from and writing to a common resource, such as table **105**, there exists a possibility that the system may be slowed as one memory management entity may have to wait for another to finish with the common resource. If the time waiting for a common resource becomes excessive, system performance can be slowed. Accordingly, it is advantageous to switch resource ownership quickly. However, switching ownership quickly may cause race conditions and resource corruption if one entity corrupts the data of another entity, for example, if data destined for one entity is interpreted by a second entity as belonging to the second entity or in the case of a race condition in which more than one MMU **109** attempts to access table **105** at the same time. Decreasing the time allotted to switching resource ownership will likely increase the possibility of race conditions between the entities, when two or more entities want to access the common resource at the same time, which can worsen the problem of resource corruption.

(23) The example distributed system, illustrated in FIG. 1, is an example of one distributed system. A virtual infinite number of different distributed systems can be designed. The present example is included to give a concrete, easily understandable example of a system in which a plurality of entities cooperate through a message-passing bus **111** in order to access a common resource, table **105**.

(24) FIG. 2 is a graphical representation of a portion of another illustrative distributed system **201**.

In distributed system **201**, a memory table **203** will be written to and read from by four computing entities: entity **1 (205a)**, entity **2 (205b)**, entity **3 (205c)**, entity **4 (205d)**. The entities **205a-d** communicate with each other via a message-passing bus **207**, which may be any type of communication channel known in the art such as a serial bus, a parallel bus or a virtual channel or the like, which is capable of passing messages between the entities.

(25) In FIG. **2**, entity **1 (205a)** initially owns memory table **203**. However, memory table **203** is a commonly owned resource whose information may be pertinent to all entities **205a-d** in the illustrative distributed system **201**. If entity **1, 205a**, is the owner of the commonly owned resource, memory table **203**, then none of the other entities **205b-d** are allowed to access memory table **203**. If an entity requires access from memory table **203** it can forward the access request to the resource owner entity **1 (205a)**, because entity **1 (205a)** owns the memory table **203** and commonly no other simultaneous access to the memory table **203** is allowed, for example, in order to prevent data coherency problems. For the purposes of this example, only the owner of a resource, i.e., the source entity, will access that resource and if other entities require data that is in the common resource, they will secure access by submitting an access request to the common resource to the current resource owner.

(26) System software (not illustrated) may dictate a change of ownership of a common resource. There are many cases where such a transfer of ownership can improve system performance.

(27) The transfer of ownership of a resource from one entity to another may cause memory coherency problems, for example, if two entities attempt to write to the same location in the memory table **203** simultaneously. Such a situation is commonly referred to as a race condition. Race conditions may be difficult to solve because such race conditions may corrupt data intermittently depending on a variety of factors. Accordingly, it is advantageous to prevent such race conditions by ensuring that only the owner of a resource can access that resource.

(28) One simple, but effective, method of avoiding a race condition while transferring ownership is to stall the entities in the system. In other words when a change of ownership of a common resource is needed, race conditions can be avoided by simply stopping all entities from accessing, e.g. reading from or writing to the common resource, until the transfer of ownership is completed. This method of course has obvious drawbacks in that all accesses of common resources are stopped whether or not it is necessary to do so.

(29) FIG. **3** is a graphical illustration of a transfer of resource ownership between entities. This method of a transfer of resource ownership solves the above-described race condition without the inefficiency of stalling the entities in the system. In FIG. **3**, entities **1** through **4 (305a through 305d** respectively) are entities that all may desire access to a common resource **311**. The entities **305a-d** pass messages to each other over a message bus of any suitable type (not shown) in order to share access to the common resource **311** by transferring ownership of the resource.

(30) The first step in the transfer of ownership, of the resource to be transferred, e.g. common resource **311**, is for the source entity (which owns the resource) to update its ownership in its common resource ownership table **313**. A common resource ownership table, such as **313**, is a list of entities in a system and what common resources are owned (able to be accessed) by each entity in the system. Each entity may contain a common resource ownership table with the same information. The common resource ownership table **313** will be updated to reflect that source entity **1 (305a)** is giving up ownership to the destination entity **305b** (i.e., entity **2**). It is helpful in avoiding race conditions for the source entity to update its common resource ownership table, before any other entity updates their common resource ownership table. Each of the entities **305a-d** in FIG. **3** has a common resource ownership table, similar to common resource ownership table **313**, which records which entity currently owns which resource. The common resource ownership tables in entities **3** and **4** are not shown to avoid cluttering FIG. **3** needlessly. Entity **1 (305a)** in the present example owns the common resource **311**. To transfer ownership of the common resource **311**, entity **1 (305a)** updates its common resource ownership table **313** to reflect the fact that it is no



longer the owner of the common resource **311**, and the destination entity **305b** is the new owner. Now any access requests for the common resource **311** coming to entity **1** (**305a**) will be forwarded to the new owner as reflected in entity **1**'s (**305a**) common resource ownership table **313**.

(31) Entity **1** (**305a**) then sends a MOVE command **307a** to the destination entity **305b** which will become the new owner of the common resource **311** once it can act on the command and update its common resource ownership table **315**. A MOVE command is also sent to the other entities in the system (e.g. **309a** and **311a**) so that their common resource ownership tables can be properly updated with new ownership of the common resources. The changing of ownership should be as close to an atomic operation as possible, that is, a change in ownership which is reflected in the common resource ownership table should take place simultaneously with the sending of the MOVE commands to other entities (e.g., **307a**, **311a**, and **309a**). However if such an atomic operation is not possible for some reason, a change in ownership should be reflected in the source entity's common resource ownership table before the MOVE command is acted on by any other entity, to ensure "thread safe" operation and thereby ensure that one thread will not corrupt another thread's data. Once each entity has changed its common resource ownership table, it may report back to the source entity that the MOVE command has been executed, e.g., **307b**, **309b** and **311b** can report that their common resource ownership tables have been updated.

(32) FIG. **4** is a flow chart illustrating the transfer of resource ownership between entities shown generally at **401**.

(33) In block **403**, the source entity **305a** which currently owns a common resource **311** receives a MOVE command **307a** from another entity, e.g., **305b**, the destination entity. Next decision block **405** is executed.

(34) In decision block **405**, the source entity **305a** determines whether accessing the common resource **311** has completed. If source entity **305a** has not completed accessing the common resource **311**, block **405** will continue to be executed. If source entity **305a** is finished with common resource **311**, execution will pass to block **407**.

(35) In block **407**, the source entity **305a** relinquishes ownership of the common resource **311** by updating its common ownership resource table **313** to reflect the fact that the destination entity **305b** owns the common resource **311**. One way to control ownership is to maintain within each entity an ownership table which lists each common resource and which entity owns the common resource and is therefore permitted to read from and/or write to (i.e. access) that common resource. In simpler systems, for example, an entity that accesses only one common resource, the common resource ownership table may be replaced by an indicator as to whether the entity owns the common resource or not. In the more complex present exemplary system, the source entity **305a** relinquishes ownership by noting, in its common resource ownership table **313**, that the common resource **311** is owned by the destination entity **305b**. Then control passes to block **409**.

(36) In block **409** the source entity **305a** sends a MOVE command (also known as a MOVE command) to the destination entity **305b** block **411** is executed next.

(37) In block **411**, the destination entity **305b** receives the MOVE command and then updates its internal common resource ownership table to reflect the fact that it is now the owner of the common resource **311**. Block **413** is executed next.

(38) In block **413**, the destination entity **305b** checks its common resource ownership table to determine if it now owns the common resource **311**. If the destination entity **305b** does not own the common resource **311**, block **415** is executed next.

(39) In block **415**, the destination entity **305b** will forward any access requests coming to it from the common resource back to the source entity and block **413** will be executed next.

(40) Of course if the source entity **305a** receives any data from the common resource it will check its common resource table **313** and once it determines that its common ownership resource table says that the common resource belongs to the destination entity **305b**, it will forward the data to the destination entity **305b**. This ping ponging between blocks **413** and **415** will be broken in block **413**

when the common resource ownership table **315** of the destination **305b** is updated so that the destination entity **305b** is the owner of common resource **311**. Then **417** will be executed next. (41) In block **417**, the destination entity **305b** has ownership of the common resource **311**, as reflected in its common resource ownership table **315** and the destination entity **305b** may proceed to access the common resource **311**.

(42) FIG. 5 is a graphical representation of a portion of an illustrative distributed system **501**. Commonly, software running in a distributed system is aware of which entity owns a particular common resource. In FIG. 5, the case is represented where software, which is executing in a first entity in a distributed system is not aware of which entity owns a particular common resource. In such a case, the MOVE command can be sent to a second entity, for example over a message passing bus which couples the first entity to the second entity. If the second entity does not own the common resource, which is the subject of the MOVE command the second entity, which received the MOVE command, will attempt to forward it to the entity that owns the particular common resource. If the second entity, which receives the MOVE command, does own the common resource, the second entity will execute the MOVE command and relinquish ownership of the common resource.

(43) In the graphical representation of FIG. 5, four entities are shown: **505a**, **505b**, **505c**, and **505d**. Each entity has a common resource ownership table **503a**, **503b**, **503c**, and **503d**, respectively.

(44) Assume, for the sake of illustration, that a MOVE command is sent to entity **3** (**505c**), which is not the current owner of the common resource whose ownership will be moved. Entity **3** may be referred to as the origination entity since that is where the MOVE command was initially sent to, i.e., originated. Assume entity **1** (**505a**) is the entity that owns the common resource, i.e., the source entity. Entity **3** should not be the first to change its mapping in its common resource ownership table **503c**. Once entity **3** (**505c**), the origination entity, examines its common resource ownership table **503c**, it will determine that (for example) entity **1** (**505a**) is the current owner (source entity) of the common resource whose ownership will be moved. Entity **3** (**505c**) will then send a MOVE FWD request **507b** to entity **1** (**505a**). Once entity **1** receives the MOVE FWD request **507b**, it can update its common resource ownership table **503a** to reflect the move of the transfer of ownership of the common resource to the destination entity **505b**. Subsequently, once entity **1** (**505a**) has updated its common resource ownership table **503a**, entity **1** (**505a**) can then send MOVE commands to entities **2**, **3**, and **4** as shown at **509b**, **507c**, and **509d** so that they may update the ownership of the transferred resources in their common resource ownership tables **503b**, **503c** and **503d**. Once entities **2**, **3**, and **4** have updated their common resource tables they can send MOVE CMPLT (MOVE complete) commands (**509c**, **511**, and **507d**) back to the entity that was the source of the MOVE command, in this example entity **3** (**505c**). Once entity **3** (**505c**), which requested the ownership change request, receives MOVE CMPLT commands (**509c**, **511**, and **507d**) from the other entities in the distributed system, it can notify the software that the requested change in common resource ownership has been completed.

(45) In certain cases there may be entities that have no need to own certain common resources, and in some cases may not even possess a common resource ownership table. For example, an entity that only accesses a printer will not require a resource ownership table. The entity simply needs an indication as to whether it currently owns the printer or not. Such entities may respond to a move command by sending a “dummy” MOVE CMPLT command to the entity which requested the move, in the present example entity **3** (**505c**).

(46) An example scenario where the source entity does not have a common resource ownership table may occur, for example, if an entity accesses only one common resource and has no access to other common resources. Just as in the example above, where an entity accesses only a single common resource, a printer, there may be entities within a system which do not have a common resource ownership table as they access a single common resource. An entity need not track a common resource it does not use.

(47) For example, assume that the source entity is entity **1 (505a)** and that common resource ownership table **503a** does not exist. A mechanism is needed to handle this situation. Again entity **3, 505c**, the origination entity, receives a MOVE command and then forwards it on to the source entity, entity **1 (505a)**. Even though entity **1 (505a)** has no common ownership resource table, as the source entity, it can still co-ordinate the ownership transfer. Once the source entity **505a** receives the MOVE command from the requesting entity **505c**, the source entity **505a** can mark the common resource as no longer available to it and create a temporary mapping (not shown). Then the source entity **505a** can send out MOVE commands (e.g., **509b, 509d** and **507c**). Once the requesting entity **505c** receives all the MOVE CMPLT commands (**509c, 511** and **507d**) from all the other entities in the system it can then inform the source entity **505a** that the resource ownership transfer is complete and send a REMOVE TEMP command **507a** to the source entity **505a** to indicate the transfer of ownership has been accomplished, and entity **1 (505a)** may remove the temporary resource mapping table. The temporary resource mapping table in this case may record the entities in the system and whether they have responded to MOVE commands (e.g. **509b, 509d** and **507c**) and have sent MOVE CMPLT commands (**509c, 511** and **507d**) to the source entity and the originator entity if appropriate.

(48) FIG. **6** is a graphical representation of a portion of an illustrative distributed system, **601**. In FIG. **6**, four entities are illustrated: entity **1 (605a)**, entity **2 (605b)**, entity **3 (605c)** and entity **4 (605d)**.

(49) Entity **1 (605a)** is the source entity. Entity **1 (605a)** contains a command queue **607**. The command queue **607** contains commands for entity **1 (605a)** to execute, such as transmit commands, which may be out of order.

(50) Assume, as in the FIG. **5**, for example, that entity **1 (605a)** receives an access request for a common resource that will be completed by entity **2 (605b)**. Assume further that common resource ownership table **603a** indicates that entity **1 (605a)** is the current owner of the resource to be accessed by entity **2 (605b)**. At some point, we can assume that entity **1's (605a)** command queue **607** will contain an access request **611**, to a commonly owned resource **615**, for entity **2 (605b)**. Entity **1 (605a)** knows that it must pass the access request **611** to entity **2 (605b)**. At some point entity **1 (605a)** will also determine that it, entity **1**, is the owner of the commonly owned resource **615** and generate a MOVE command **609** to move the ownership of the commonly owned resource **615** to entity **2 (605b)**. It is entirely possible that the access request **611** may be scheduled to transmit to entity **2 (605b)** prior to MOVE command **609**. If the access request **611** arrives at entity **2 (605b)** before the MOVE command **609**, then entity **2 (605b)** the destination will simply forward the access request **611** back to entity **1 (605a)** as shown at **613**. However, if entity **1 (605a)** can detect that it will be sending both an access request **611** and a MOVE command **609** for a commonly owned resource **615** to a common entity, it will be more efficient to send the MOVE command **609** first.

(51) If the access request **611** is sent to the destination entity **605b** prior to the MOVE command **609** being sent to the destination entity **605b**, the destination entity **605b** may examine its common resource ownership table **603b** and determine that the common resource **615** is owned by source entity **605a** and forward **613** the access request **611** to a previous owner of the commonly owned resource **615**, in this case the source entity **605a**. However, if the MOVE request **609** is sent from the source entity **605a** prior to sending the access request **611** the destination entity **605b** will update its common ownership resource table before getting the access request **611**. The destination entity **605b** will determine that it owns the common resource **615** and it is free to access the common resource **615**.

(52) In the case that the access request **611** is sent to the destination entity **605b** prior to the MOVE command **609** the access request **611** is forwarded at **613** back to the source entity **605a**, the source entity **605a** will examine its common resource ownership table **603a** and then forward the access request **611** back to the destination entity **605b**, i.e., entity **2**. Accordingly, if entity **1 (605a)** detects

that there is both a MOVE command **609**, transferring the ownership of a common resource to a destination entity **605b**, and a command that is an access request **611** for the common resource on behalf of the destination entity **605b** in the command queue **607**, it will be advantageous for entity **1** (**605a**) to ensure that the MOVE command **609** is sent and arrives at the destination entity **605b** before the access request **611** arrives at the destination entity **605b**, which will ensure the destination entity **605b** has already updated its common resource ownership table **603b**. Once the ownership of the common resource **615** has been relinquished by source entity **605a** and that the destination entity **605** updates its common resource ownership table **603b** the destination entity **605b** owns the common resource. Once the destination entity **605b** owns the common resource **615** it will complete the access request **611** and no longer forward the access request at **613**.

(53) Those of skill in the art will appreciate that information and signals may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the above description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

(54) Further, those of skill in the art will appreciate that the various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the aspects disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present invention.

(55) The methods, sequences and/or algorithms described in connection with the aspects disclosed herein may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module may reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, hard disk, a removable disk, a CD-ROM, or any other form of storage medium known in the art. An exemplary storage medium is coupled to the processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor.

(56) Accordingly, an aspect of the invention can include a computer-readable non-transitory media embodying a method for managing allocation of a cache. Accordingly, the invention is not limited to illustrated examples and any means for performing the functionality described herein are included in aspects of the invention.

(57) While the foregoing disclosure shows illustrative aspects of the invention, it should be noted that various changes and modifications could be made herein without departing from the scope of the invention as defined by the appended claims. Furthermore, although elements of the invention may be described or claimed in the singular, the plural is contemplated unless limitation to the singular is explicitly stated.

## Claims

1. A method of controlling access to a common resource in a distributed system, the method comprising: transmitting, from a source entity to a destination entity, an indication that the ownership of a common resource is to be moved from the source entity to the destination entity; generating, by a non-source entity, a request to access the common resource, wherein the non-source entity is not a current owner of the common resource; transmitting, by the non-source entity, the access request to the source entity; generating an access of the common resource by the source

entity; and forwarding, by the source entity, the access request to the destination entity subsequent to transmitting the indication, wherein the source entity, the non-source entity, and the common resource are implemented in hardware as dies.

2. The method of claim 1, wherein transmitting the access request to the source entity further comprises sending the access request via a message-passing bus.

3. The method of claim 2, wherein the message-passing bus physically connects the source entity and the non-source entity.

4. The method of claim 1, wherein only an owner of the common resource is allowed to access the common resource, and wherein the ownership of the common resource is transferable between the source entity and the non-source entity.

5. The method of claim 1, wherein the source entity, the non-source entity, and the common resource are all formed on a carrier substrate.

6. The method of claim 1, wherein the source entity includes a common resource ownership table associated with the source entity, wherein the non-source entity includes a common resource ownership table associated with the non-source entity, and wherein the method further comprises: the source entity maintaining its common resource ownership table with information on ownership of the common resource; and the non-source entity maintaining its common resource ownership table with information on ownership of the common resource.

7. The method of claim 6, wherein when the ownership of the common resource changes from the source entity to another entity, the source entity updates its common resource ownership table before the another entity updates its common resource ownership table.

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