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(54) **POWER EFFICIENT MEDIA PLAYBACK ON GENERAL PURPOSE PORTABLE DEVICES**

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(52) **U.S. Cl.** **711/118**

(57) **ABSTRACT**

A portable multifunction computing device optimizes cache storage when processing media files and the like. During a playback operation, the device caches as many media items as possible such that during playback media items are retrieved from cache rather than from a hard disk memory. The device monitors memory requirements of other programs and applications currently in use on the device to insure sufficient cache memory is available for such programs and applications.

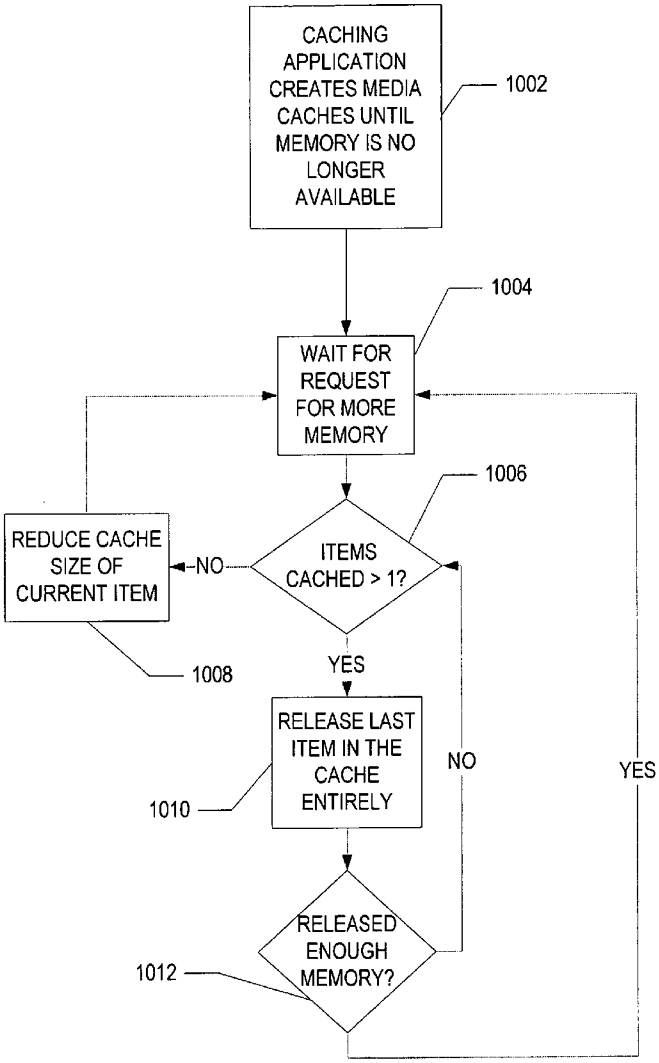

CACHING APPLICATION CREATES MEDIA CACHES UNTIL MEMORY IS NO LONGER AVAILABLE
1002
1004
WAIT FOR REQUEST FOR MORE MEMORY
1006
REDUCE CACHE SIZE OF CURRENT ITEM
NO
ITEMS CACHED > 1?
1008
YES
RELEASE LAST ITEM IN THE CACHE ENTIRELY
NO
YES
1010
RELEASED ENOUGH MEMORY?
1012

FIG. 1

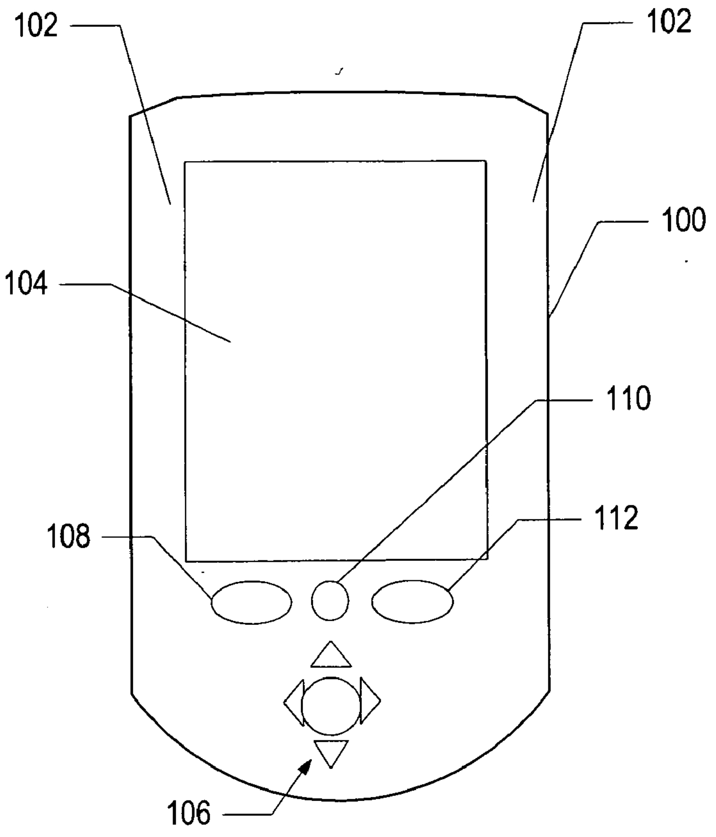


FIG. 2

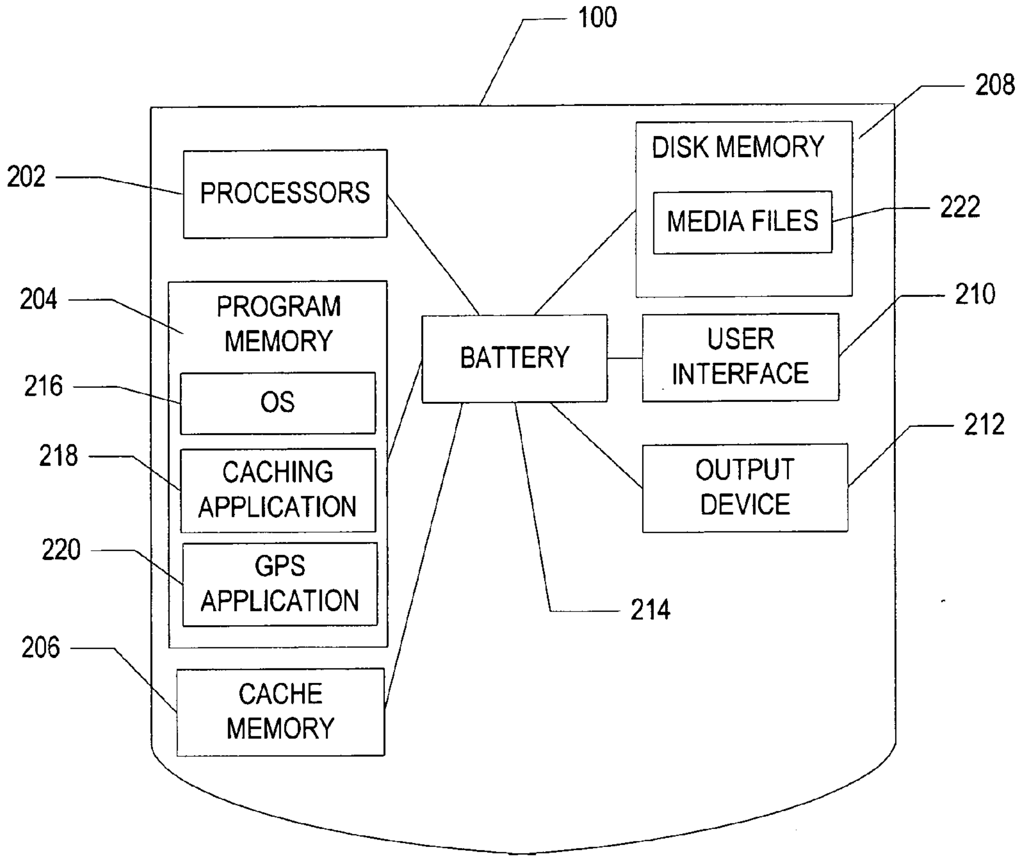

100
208
202
PROCESSORS
DISK MEMORY
MEDIA FILES
222
204
PROGRAM MEMORY
210
216
OS
BATTERY
USER INTERFACE
218
CACHING APPLICATION
212
OUTPUT DEVICE
220
GPS APPLICATION
214
206
CACHE MEMORY

FIG. 3

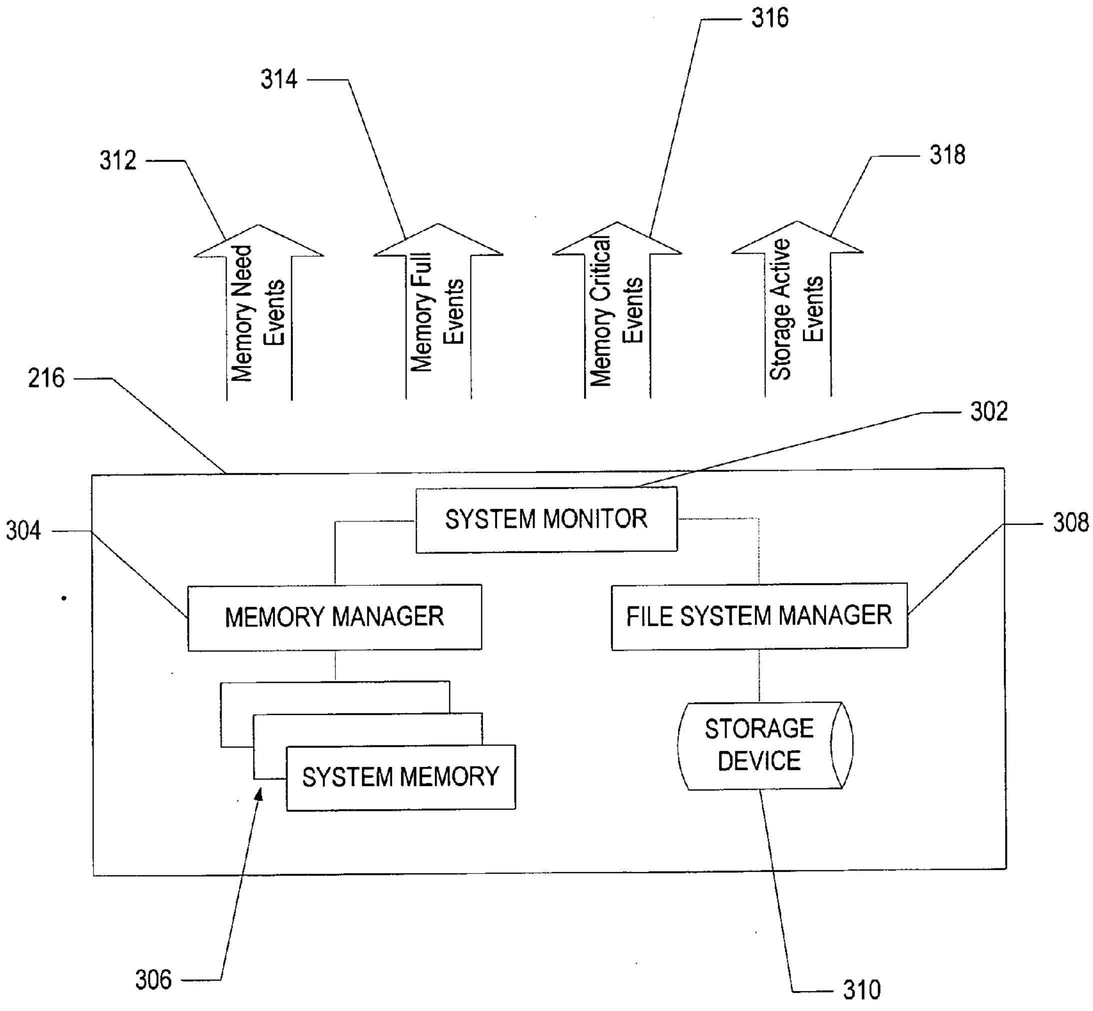

316
314
312
318
Memory Need Events
Memory Full Events
Memory Critical Events
Storage Active Events
216
302
SYSTEM MONITOR
304
308
MEMORY MANAGER
FILE SYSTEM MANAGER
SYSTEM MEMORY
STORAGE DEVICE
306
310

FIG. 4

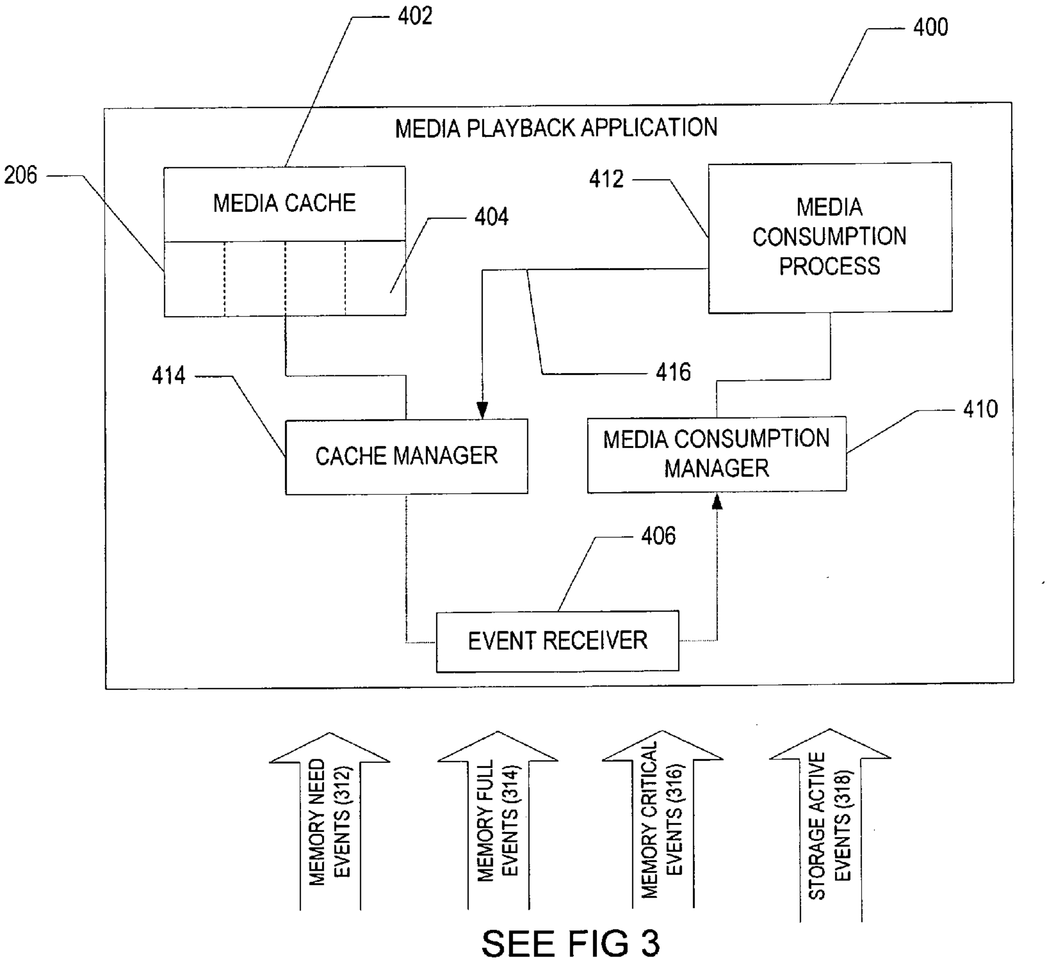
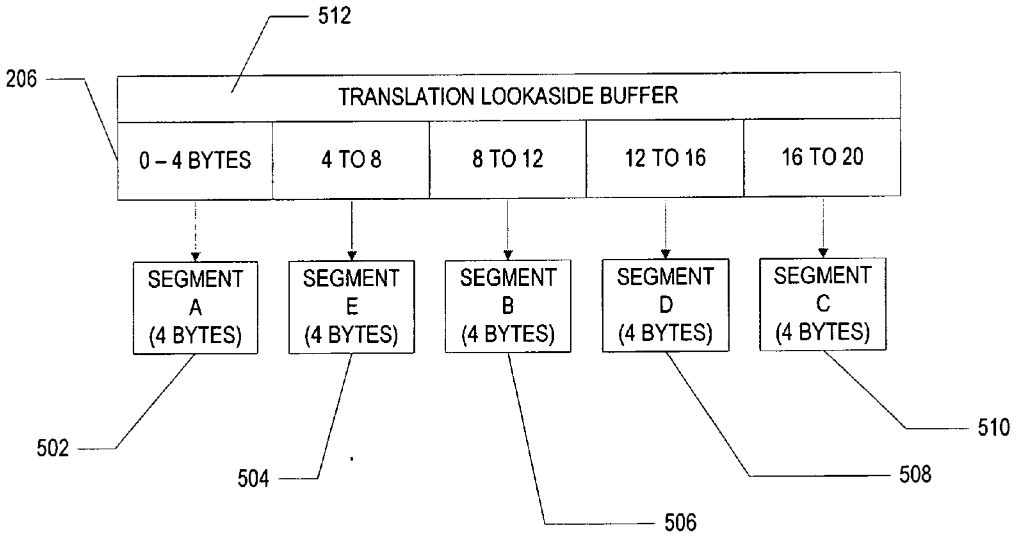

402
400
MEDIA PLAYBACK APPLICATION
206
MEDIA CACHE
404
412
MEDIA CONSUMPTION PROCESS
416
414
CACHE MANAGER
MEDIA CONSUMPTION MANAGER
410
406
EVENT RECEIVER
MEMORY NEED EVENTS (312)
MEMORY FULL EVENTS (314)
MEMORY CRITICAL EVENTS (316)
STORAGE ACTIVE EVENTS (318)
SEE FIG 3

FIG. 5


512
206
TRANSLATION LOOKASIDE BUFFER
0 – 4 BYTES
4 TO 8
8 TO 12
12 TO 16
16 TO 20
SEGMENT A (4 BYTES)
SEGMENT E (4 BYTES)
SEGMENT B (4 BYTES)
SEGMENT D (4 BYTES)
SEGMENT C (4 BYTES)
502
504
506
508
510

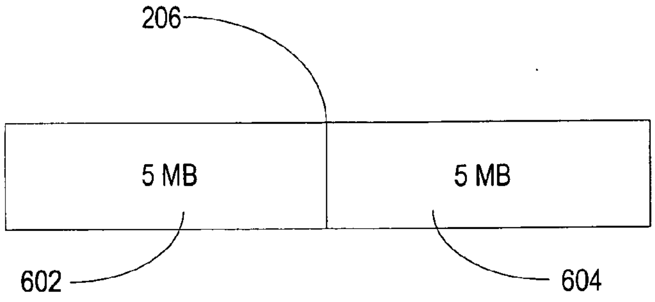


FIG. 6A

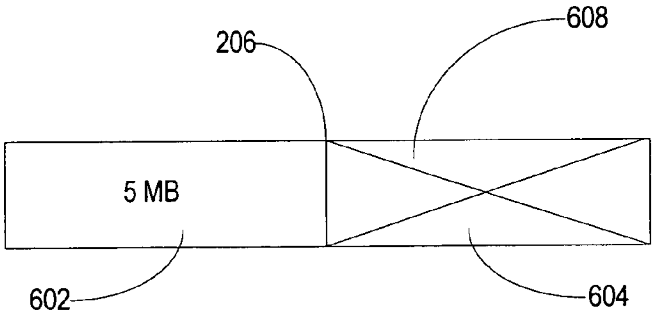


FIG. 6B

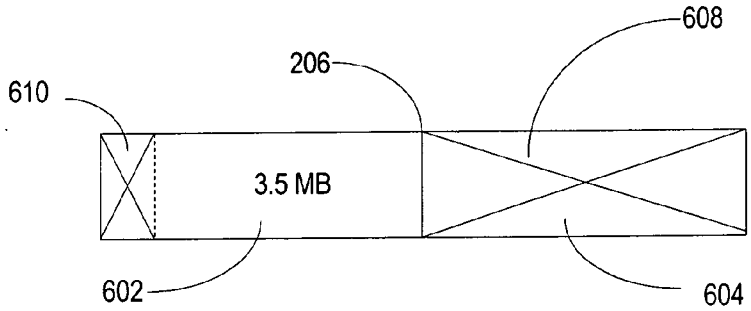


FIG. 6C

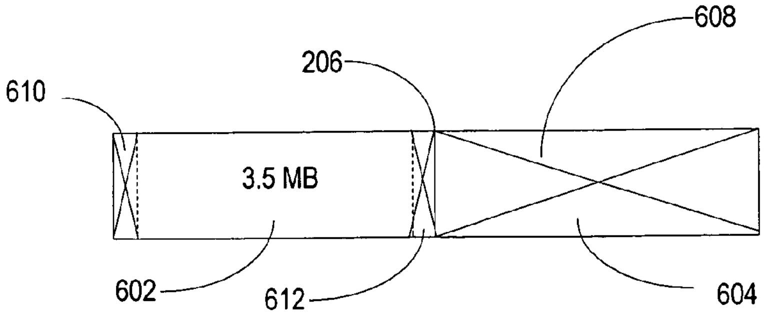


FIG. 6D

FIG. 7

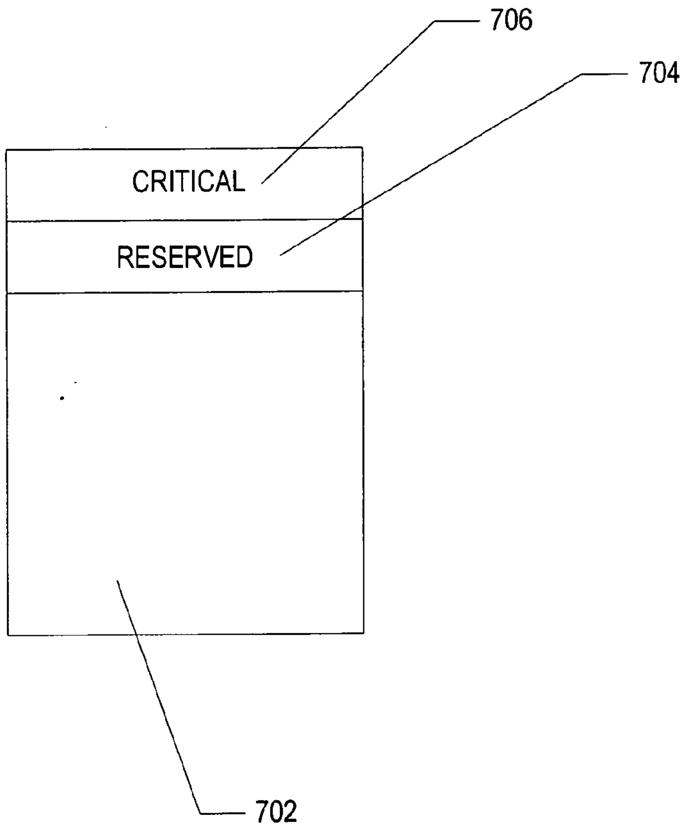


FIG. 8

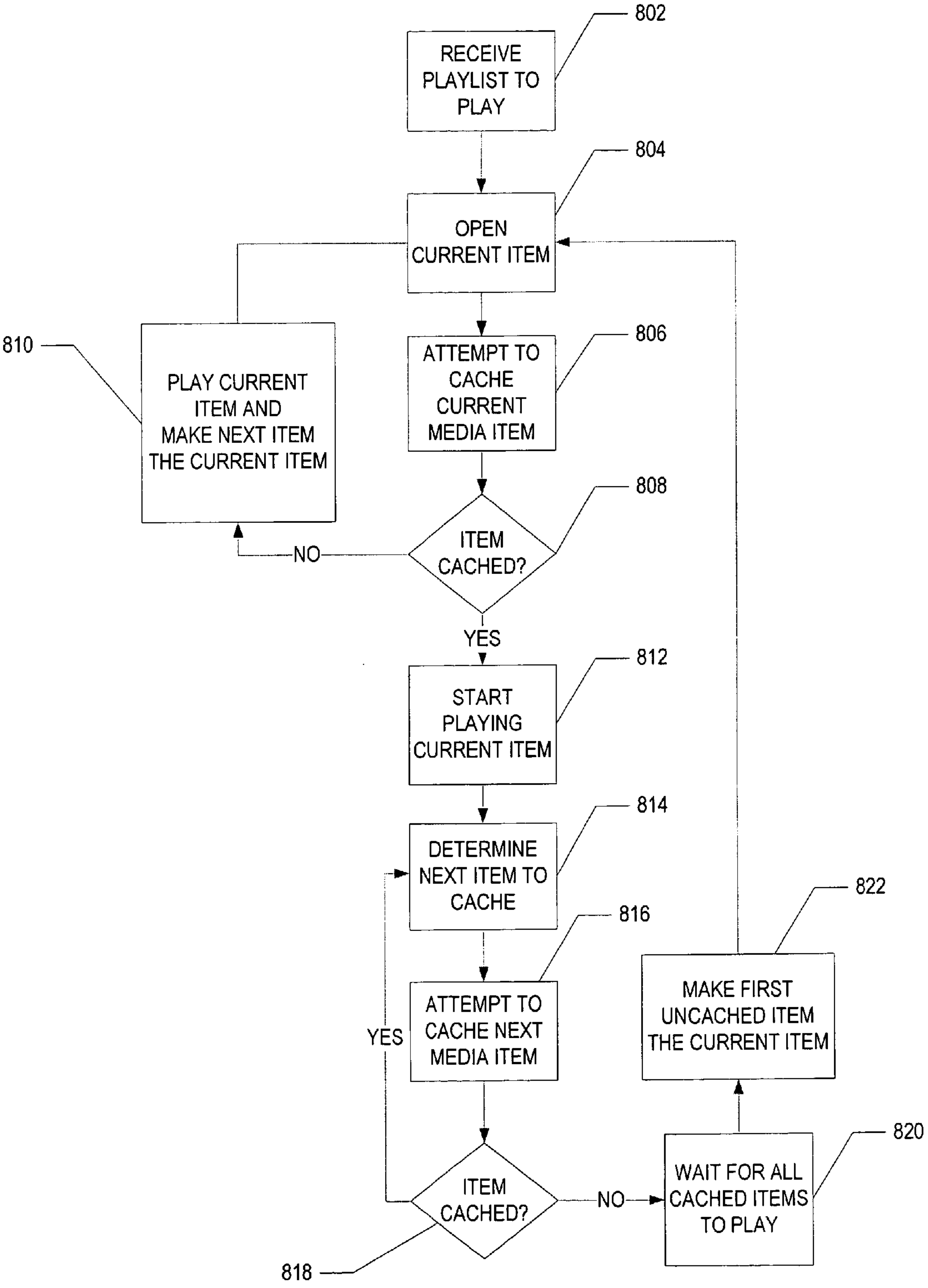

802
RECEIVE PLAYLIST TO PLAY
804
OPEN CURRENT ITEM
806
ATTEMPT TO CACHE CURRENT MEDIA ITEM
808
ITEM CACHED?
NO
YES
810
PLAY CURRENT ITEM AND MAKE NEXT ITEM THE CURRENT ITEM
812
START PLAYING CURRENT ITEM
814
DETERMINE NEXT ITEM TO CACHE
816
ATTEMPT TO CACHE NEXT MEDIA ITEM
YES
818
ITEM CACHED?
NO
820
WAIT FOR ALL CACHED ITEMS TO PLAY
822
MAKE FIRST UNCACHED ITEM THE CURRENT ITEM

FIG. 9

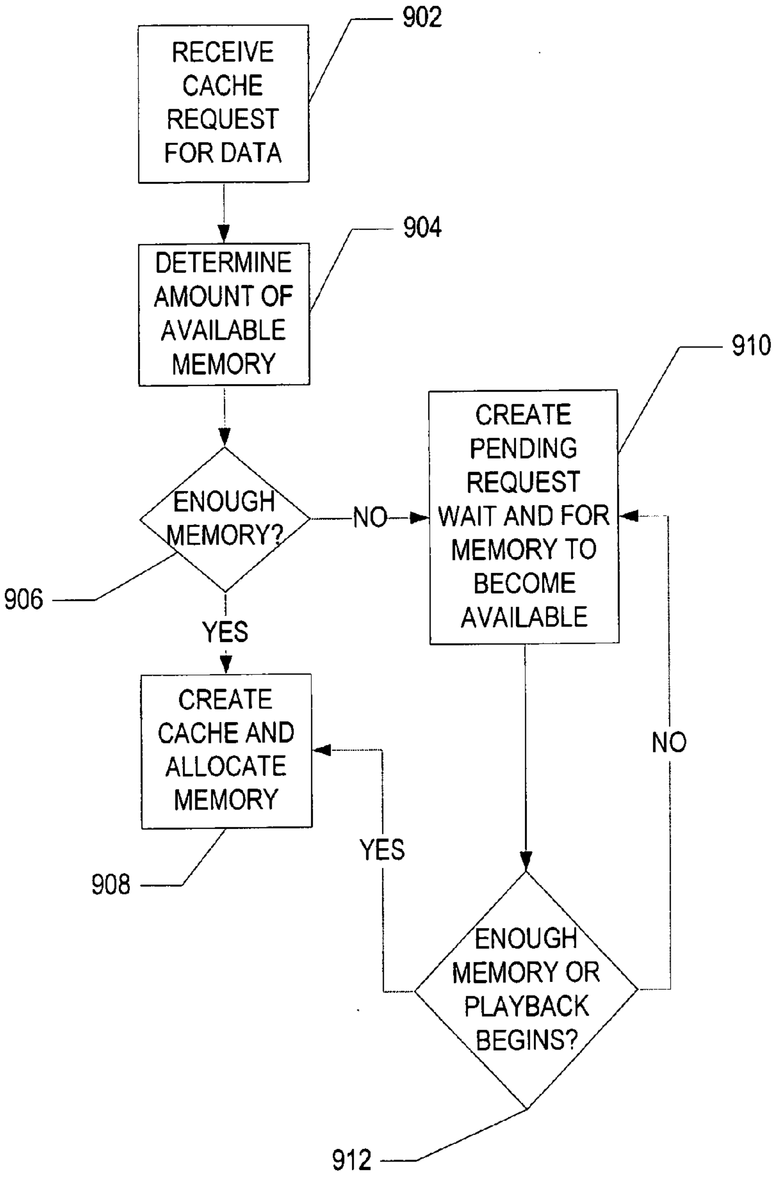
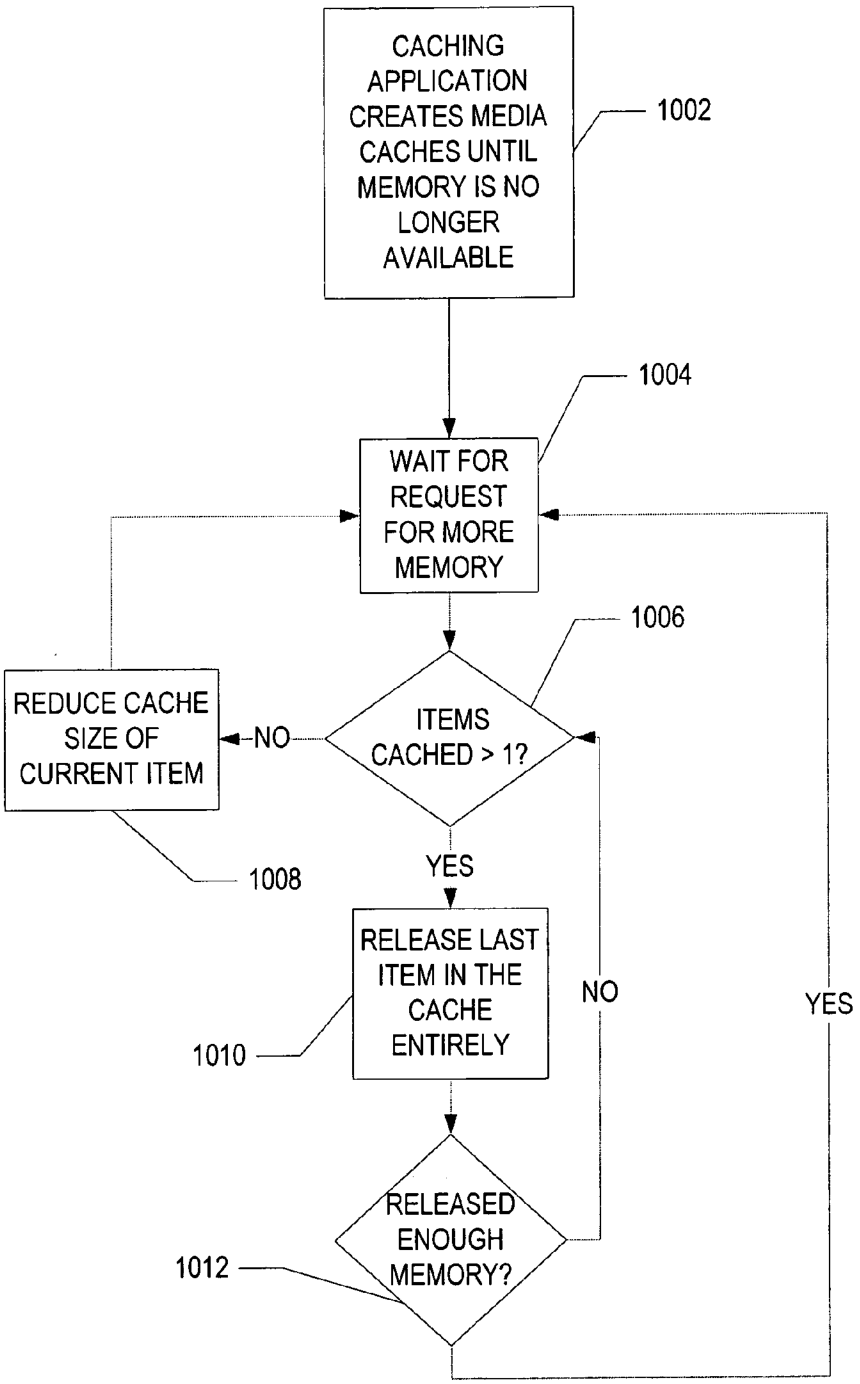

RECEIVE CACHE REQUEST FOR DATA
902
DETERMINE AMOUNT OF AVAILABLE MEMORY
904
910
CREATE PENDING REQUEST WAIT AND FOR MEMORY TO BECOME AVAILABLE
ENOUGH MEMORY?
NO
906
YES
CREATE CACHE AND ALLOCATE MEMORY
NO
YES
908
ENOUGH MEMORY OR PLAYBACK BEGINS?
912

FIG. 10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1004
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1006
ITEMS CACHED > 1?
NO
REDUCE CACHE SIZE OF CURRENT ITEM
1008
YES
RELEASE LAST ITEM IN THE CACHE ENTIRELY
1010
NO
YES
RELEASED ENOUGH MEMORY?
1012

POWER EFFICIENT MEDIA PLAYBACK ON GENERAL PURPOSE PORTABLE DEVICES

BACKGROUND

[0001] Portable computing devices are commonplace and widespread in their use. Some of these devices are capable of doing only a singular function, or fixed purpose. Most digital watches, for example, are only capable of performing simple operations around time or possibly doing simple arithmetic. Although they may be able to serve as an alarm clock, stopwatch, timer, or calculator, everything is still controlled by a single process whose capabilities are limited to the tasks defined when the watch was designed and produced. It is realistic to consider that the designers of a fixed purpose device can evaluate all of the behaviors of the device and guarantee that the device always functions correctly.

[0002] In addition to fixed purpose devices, multifunction, or general purpose, portable computing devices are very prevalent. These devices allow users to, for example, play movies, music, video games, and/or other types of media from an internal or external memory. These devices also support additional functions, such as those associated with cellular phones, portable digital assistants (PDAs), and traditional desktop computing (notebooks). Unlike fixed purpose devices, multifunction devices are typically set apart by having an operating system which provides a platform upon which the original designers or third parties may extend the functionality of the device. Because the designers are not able to determine all of the different tasks the device will ever perform they cannot guarantee that the device always functions correctly. This responsibility is now shared by all individuals who choose to extend the functionally of the device. The devices come in many shapes and configurations, and offer a wide variety of functionality.

[0003] Portable computing devices of this type are commonly equipped with solid state memories (e.g. non-volatile RAM (random access memory) or flash memory) to store the media. However, these devices are limited in the amount of media that can be stored. To increase storage capacity, a device can be equipped with hard disk memory that is capable of holding large quantities of media, such as full-length movies and extensive music libraries. The drawback of using hard disk memory is that accessing content is slower and less responsive in comparison to solid state memory. Thus, users may encounter noticeable delays between the time they select play and the time music is heard or video seen, resulting potentially in an unsatisfactory user experience. Additionally, accessing content on the hard disk memory typically consumes more power than accessing content in solid state memory. For example, digital media playback can be a CPU and file system intensive task. Both of these systems can place significant demands on the overall power requirements of a computer. In contrast, this is typically not a significant issue on a desktop computer because it has a constant power supply readily available. However on portable devices, where battery power is the primary source, problems occur. The heavy demands placed on the battery by the CPU and the different devices used to store data can severely limit the overall battery life of the device and its attractiveness to the consumer.

[0004] Designers of portable computing devices and those who write software to extend multifunction devices are therefore faced with a number of competing design challenges, including maximizing battery life, providing a responsive user interface for a satisfactory user experience, and supporting extended periods of playback. Designers have been generally resigned to satisfying one or possibly two of these challenges, while sacrificing the others. But, with each generation of devices, consumers demand more.

SUMMARY

[0005] Aspects of the invention allow for the management of a cache memory of a portable multifunction computing device such that data to be processed by an application executing on the device is retrieved from one or more cache segments. In one embodiment, a caching application manages the storage and retrieval of media to and from the cache segments based on the size of the media and caching opportunity determined by monitoring memory and other requirements from other applications executing on the portable multifunction device. Accordingly, the device can offer an enhanced user experience while minimizing hard disk access, thereby conserving power and maximizing battery life, and ensure that all applications have adequate memory available to perform their intended functions.

[0006] This summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

[0007] Other features will be in part apparent and in part pointed out hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. **1** is an exemplary embodiment of portable multifunction computing device which the invention may be implemented.

[0009] FIG. **2** is an exemplary block diagram illustrating components of a portable multifunction computing device.

[0010] FIG. **3** is an exemplary block diagram illustrating memory management components of a portable multifunction computing device.

[0011] FIG. **4** is an exemplary block diagram illustrating components of a caching application.

[0012] FIG. **5** is an exemplary block diagram illustrating a segmented memory cache.

[0013] FIGS. **6**A-**6**D illustrates various storage states of a segmented memory cache.

[0014] FIG. **7** is an exemplary block diagram illustrating a partitioned memory.

[0015] FIG. **8** is an exemplary flow chart illustrating for caching media in a cache memory of a portable multifunction computing device according to one exemplary embodiment of the invention.

[0016] FIG. **9** is an exemplary flow chart illustrating a method for processing a playlist of media files from the cache memory of a portable multifunction computing device according to one exemplary embodiment of the invention.

[0017] FIG. **10** is an exemplary flow chart illustrating a method for responding to low memory conditions in a portable multifunction computing device processing cache request according to one exemplary embodiment of the invention.

[0018] Corresponding reference characters indicate corresponding parts throughout the drawings.

DETAILED DESCRIPTION

[0019] FIG. **1** shows a portable multifunction computing device **100** capable of performing multiple functions, such as playing music and videos, depicting digital photos, downloading content from the Internet, and the like. In the illustrated embodiment, the device **100** has a body or casing **102** and a display panel **104** located centrally within the casing **102**. The display panel **104** is, for example, a flat panel, color display with sufficient resolution to depict digital images or motion video. The display panel **104** may optionally be implemented with an overlaid touch screen to facilitate user input. The display panel **104** may be implemented using different technologies, including LCD (liquid crystal display), OLED (organic light emitting diode), plasma, and DLP (digital light processing).

[0020] Function control buttons **106** are positioned relative to the display panel **104** to support user control of the device **100**. In the illustrated implementation, the control buttons **106** include four directional buttons and an entry key. Buttons **108**, **110**, and **112** are positioned above the control buttons to facilitate additional navigation within the user experience. One or more other buttons may also be provided to permit control of other functions, such as shuttle, volume, brightness, contrast, and so forth. It is noted that the device **100** is just one exemplary implementation, and that other configurations and physical layouts, with more or less buttons and features, may be used.

[0021] The display panel **104** (and optional touch screen) and buttons **106**, **108**, **110**, and **112** provide a user interface (UI) to facilitate user interaction with the device **100**. The screen shows, for example, a playlist and menu options, while the hard or soft-key buttons facilitate navigation of the menu, selection of items on the menu, and entry of control commands (e.g., shuttle controls, volume, etc.).

[0022] FIG. **2** shows selected operational components of the portable multifunction computing device **100**. The device **100** includes one or more microcontrollers or processors **202**, a program memory **204** (e.g., ROM, flash, NVRAM, etc.), a cache memory **206** (e.g., RAM), a hard disk memory **208**, a user interface **210**, output components **212**, and a battery **214**. The processor(s) **202** may include general-purpose processors and/or special-purpose processors, such as graphics processors. It is noted that other configurations are possible. Typically cache memory **206** is included as part of program memory **204** (rather than separate as shown). Alternative embodiments of device **100** where dedicated cache memory **206** is available are applicable to the embodiments of the invention described herein when cache memory **206** is a shared resource that may be either assigned dynamically as program memory **204** or shared among more than one caching application.

[0023] Program memory **204** is typically partitioned to store both instructions to be executed by the processor(s) **202** and data representing the current state of the different programs being executed. In this illustration, the instructions and state data for an operating system **216**, an intelligent media caching application **218**, and a GPS (Global Positioning System) application **220** are stored in program memory **204** and executed on the processor(s) **202**. Simultaneous execution of multiple applications stored in program memory **204** is under the control of OS **216** and may proceed in either a cooperative or preemptive multitasking fashion. The battery **214** supplies power to the components of the computing device **100**. The battery **214** is preferably a rechargeable battery, such as a lithium-based battery.

[0024] In one embodiment, the disk memory **208** stores media **222**. There are many types of media, including video content (e.g., movies, TV programs, home videos, etc.), music content, digital photos, video games, and the like. The media **222** is stored as individual files that can be accessed and played by applications stored in program memory **204** using processor(s) **202**. The disk memory **208** has sufficient capacity to store many media files, and has substantially more storage capacity than cache memory **206**. For instance, in certain implementations, the disk memory **208** may hold a library of music titles or short video clips, whereas cache memory **206** is sufficiently large to store only several minutes of audio or video information. Notably, the contents of disk memory **208** are not limited to media files **222**. As space becomes available, other applications (e.g., GPS application **220**) may persist information in disk memory **208**. In general, hard disk memory **208** is exemplary of any computer readable storage medium that due to its standard method of input requires more power than other storage mediums to perform its functions. For example, in addition to traditional hard disk memory this may include optical storage devices or any other device where the storage medium is mechanically spun.

[0025] The user interface (UI) **210** facilitates user interaction with the device. The UI **210** in one embodiment includes a graphical user interface depicted on the display panel **104**, and hard-key buttons **106**-**112** that allow user control. It might also include a touch screen overlaid on the display panel **104**. With the UI **210**, a user in the context of caching application **218** can browse through playlists of the media **224** stored in the disk memory **208** and select individual media items for playback. It is assumed that the OS **216** enables the user to choose between the different available UI contexts represented by the applications stored in program memory **204**. For example, the user may elect to switch the user experience context from media caching and playback application **218** to GPS application **220**. The output components **212** generate the audible sounds or visible images when the media items are played. These components might include, for example, audio outputs (e.g., speaker, speaker output port, etc.), display outputs, and/or the display panel **104**.

[0026] According to one embodiment of the present invention, the cache memory **206** is sufficiently sized to hold snippets or portions of a large media file **222**, or contiguous media within one or more sequential files. During play, the processor **202** reads from the cache memory **206** under control of caching application **218**. That is, rather than reading media **222** from the disk memory **208** as media is read out from the cache, the subsequent media file in the playlist is also read from the cache **206**. In this manner, the operation of heavy power consuming devices such as the motors that spin the disk upon which the disk memory is stored can be reduced. Additionally any disruption to disk operation caused by activity (e.g. jogging, skiing, etc.) will not affect performance. As media is read out for processing, cache memory **206** is made available for other media. Only when caching application **218** determines that more media must be read from disk memory **208** and placed in the cache memory **206** does the process of refilling caching memory **206** begin. Moreover, the media caching program monitors memory requirements of other programs and applications such as the GPS application **220** currently in use on the portable multifunction computing device **100** to ensure sufficient cache memory is available for such programs and applications. By caching as much media as possible prior to processing, for example, a playlist, while ensuring sufficient cache memory is available for other active programs and applications, the power demands placed on the battery **214** by the processors **202** and storage device (e.g., disk memory **208**) are reduced. Thus, the overall battery **214** life of the device **100** can be extended.

[0027] The device **100** typically has at least some form of computer readable media. Computer readable media, which include both volatile and nonvolatile media, removable and non-removable media, may be any available medium that may be accessed by computer **100**. By way of example and not limitation, computer readable media comprise computer storage media and communication media. Computer storage media include volatile and nonvolatile, removable and non-removable media implemented in any method or technology for storage of information such as computer readable instructions, data structures, program modules or other data. For example, computer storage media include RAM, ROM, EEPROM, flash memory or other memory technology, CD-ROM, digital versatile disks (DVD) or other optical disk storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium that may be used to store the desired information and that may be accessed by device **100**. Combinations of any of the above are also included within the scope of computer readable media.

[0028] For purposes of illustration, programs and other executable program components, such as the operating system, are illustrated herein as discrete blocks. It is recognized, however, that such programs and components reside at various times in different storage components of the computer, and are executed by the data processor(s) of the computer.

[0029] Embodiments of the invention may be described in the general context of computer-executable instructions, such as program modules, executed by one or more computers or other devices. Generally, program modules include, but are not limited to, routines, programs, objects, components, and data structures that perform particular tasks or implement particular abstract data types. Aspects of the invention may also be practiced in distributed computing environments where tasks are performed by remote processing devices that are linked through a communications network. In a distributed computing environment, program modules may be located in both local and remote computer storage media including memory storage devices.

[0030] Referring now to FIG. **3**, a block diagram illustrating components of a portable multifunction computing device operating system **216** for monitoring and reporting state information. System monitor **302** represents an abstraction for zero or more discrete operating system functions that monitor different pieces of information about the state of operating system **216**. Those skilled in the art will readily recognize that system monitor **302** need not correspond directly to a single identifiable function of operating system **216**. In one embodiment, the system monitor **302** may be a collection of APIs capable of providing information about the current state of the different components of multifunction device **100** that may be checked at regular polling interval by applications (e.g., operating system **216**, caching application **218** and GPS application **220**) executing on processor **202**. In such embodiments, the applications themselves fulfill the responsibilities typically reserved for system monitor **302**.

[0031] In an alternative embodiment, the system monitor **302** includes a specific operating system component capable of sending events to interested applications. There is no requirement that these events be sent in a synchronous fashion causing operations to wait until all interested applications have processed the events. In this environment, the different applications executing on processor **202** have the option of requesting notifications from system monitor **302**. Depending on implementation decisions made by the author of operating system **216** and the processing environment of device **100** applications may communicate directly with system monitor **302** or one of its components to complete this registration process. For example, in one embodiment system monitor **302** may provide a function that can be called by applications executing on processor **202** to request notifications from system monitor **302**. Alternative embodiments may allow applications to specify the exact notifications they are interested in receiving. Different embodiments of system monitor **302** may dedicate an area of storage, in program memory **204**, cache memory **206**, disk memory **208**, or other areas which change when an event takes place. Applications wishing to receive notifications from system monitor **302** simply check the value of this location and, if changed, recognize that system monitor **302** has sent a notification. Other methods for sending notifications from one component to another component exist and the descriptions provided here are not intended to restrict communication from system monitor **302** to interested applications to just the examples provided. In addition, other models exist for applications determining the state of different operating system components and where those models provide the information described as part of this invention they are recognized as applicable embodiments.

[0032] Typically the memory manager **304** of operating system **216** is capable of allocating and de-allocating memory for use by the different applications (e.g. operating system **216**, caching application **218** and GPS application **220**) executing on processor **202** of portable multifunction device **100**. Since the memory systems of multifunction device **100** is a finite resource, memory manager **304** is also responsible for denying requests for memory made by applications executing on processor **202**. While the fact that memory manager **304** may deny requests for memory is important, the specific manner in which applications other than caching application **218** executing on processor **202** respond to being denied memory is beyond the scope of this invention. A system monitor **302** is configured to monitor the state of memory manager **304** and report changes in state to applications configured to listen to the events **312**, **314**, and **316** generated by system monitor **302**. When an application (e.g. GPS application **220**) requests a block of system memory **306** from memory manager **304**, memory manager **304** may discover that there is not enough system memory **306** available to respond to the request. This state does not indicate that all memory requests cannot be fulfilled only that the specific request being handled cannot be fulfilled from the available memory. Memory manager **304** then actively or passively notifies system monitor **302** of this fact. At which point system monitor **302** may send an event or otherwise signal interested applications executing on processor **202** that a memory need event **312** has occurred. Applications which receive this notification may take action on the event to release memory currently allocated by them to make more memory available to memory manager **304** to fulfill the request. As applications use memory, memory manager **304** may reach a point where it decides based on an unspecified process that there is no more memory available in the system for general distribution to requesting applications. This state does not imply that all memory within the system is allocated. Rather it indicates that the system has reached a state in which the memory that remains reasonably needs to be reserved for safe operation. When memory manager **304** determines that this is the case it will notify system monitor **302** through active or passive means that a memory full event **314** needs to be sent. Applications listening to the memory full event **314** may choose to release memory back to the system to relieve the pressure being felt by the system memory **306**. If the pressure is not released and the remaining memory is consumed by new requests, memory manager **304** will actively or passively notify system monitor **302** that a memory critical event **316** needs to be sent. This event indicates that the system is running dangerously low on memory and that system stability may come into question. Again applications listening to memory critical events **316** are free to determine how they respond but the hope is that they will release memory back to the system so that it can continue to operate safely. Again alternate embodiments of system monitor **302** and memory manager **304** may exist which define different events when available memory in system memory **306** becomes low. Provided that caching application **218** is able to determine these states and respond to them they are considered applicable to this invention.

[0033] In addition to memory manager **304**, a file system manager **308** is a known operating system feature that controls access to data stored on storage device **310** (e.g., hard disk memory **208**). Through file system manager **302** applications executing (e.g., operating system **216**, caching application **218**, and GPS application **220**) on processor **202** of device **100** read file data from and/or write file data to storage device **310**. In one embodiment, a system monitor **302** actively or passively receives information from file system manager **302** about the state of activity on storage device **310**. Based on this information it may send events to interested applications that have registered with system monitor **302**. In one embodiment, caching application **218** is particularly interested in the storage active event **318**. This event indicates that storage device **310** has started to draw more power in response to a request made through the file system manager **308**. Support for storage active event **318** is not a fundamental requirement of this invention but in multifunction devices where significant access to hard disk memory **208** is made by applications other than caching application **218** it is a recommended feature.

[0034] Referring now to FIG. **4**, a block diagram illustrates components of a media playback application **400** (e.g., caching application **218**) for managing cache memory (e.g., cache memory **206**) for playback of digital media according to one embodiment of the invention. A cache management component **414** segments the cache memory **206** to define media cache(s) **402** for the different items that need to be cached. Since caching application **400** needs to respond to memory usage events **312**, **314**, and **316** from system manager **302** a simple caching model where a single block of memory sized large enough to hold the item being cached is not sufficient. To enable the caching application **400** to respond to these events, each media cache **402** is made up of a collection of cache segments **404**. These segments may be added or removed from the media cache in response to memory usage events. Typically the storage capacity of each cache segment **404** is determined by empirical modeling and then pre-programmed into the cache defining component **402**. The number of segments required to cache a particular item is determined based on the item being cached in media cache **402** and the amount of cache memory available.

[0035] Referring briefly to FIG. **5**, an exemplary block diagram illustrates the segmentation of a media cache **402** into a subset of five cache segments (e.g., Segment A **502**, Segment E **504**, Segment B **506**, Segment C **508**, and Segment D **510**). Consider that the item being cached by media cache **402** is 18 megabytes in size and that each cache segment is capable of storing 4 megabytes. In order to accommodate the item a total cache of 20 megabytes is required since segments are of a fixed size and cannot be partially allocated. Because the cache segments **404** may be allocated at different times there is no guarantee that the memory holding the first 4 megabytes of data is contiguous with the memory holding the next 4 megabytes of data. This is the case in FIG. **5** where segment E **504** was allocated after segments A **502**, B **506**, C **508**, and D **512** but is storing the second 4 megabyte block of data from the file. To deal with the fact that the cache is made up of segments of potentially non-contiguous data, a translation lookaside buffer (TLB) **512** can be used to map between request for a particular range of data and the cache segments storing that data. This is similar to how hardware memory caches are typically implemented in CPUs. In examining TLB **512** note that it contains pointers to each of the cache segments making up media cache **402**. When a request is made for the data located at a particular offset in the cache, for example the 128 bytes found starting at an offset of 10 MB, the first operation is to determine which cache segment contains the data. In the simplest embodiment this is done by creating an array of pointers to the cache segments. The value of the item stored at the starting index of the array points to the first cache segment, the value of the next index points to the next cache segment, and so on. To determine which cache segment contains the desired offset, an integer divide of the offset by the size of each cache segment is performed. The resulting integer value may be added to the starting index of the array to locate the segment that holds the offset being requested. Returning to the example above, an integer divide of 10 MB by 4 MB is performed yielding 2 indicated that the desired value is in the third segment (starting offset+2). Once the segment is located it is necessary to determine the location within the segment where the requested offset is located. To do this the product of the integer value determined by dividing the offset by the segment size is multiplied by the segment size and then subtracted from the offset. This new result provides the location in the segment. Again returning to the example, the yielded 2 is multiplied by 4 MB yielding 8 MB which is then subtracted from 10 MB yielding 2 MB. The desired offset is located 2 MB into the third segment in the cache. Note that as data is retrieved from the different segments care must be taken to make sure that blocks of data requested which extend across segment boundaries are correctly located and returned. Alternative embodiments of a simple array based translation buffer exist which are designed to reduce the overall memory requirements of media cache **412** when it is sparsely populated.

[**0036**] Referring back to the illustrated embodiment of FIG. **4**, a media consumption manager **410** is defined which is responsible for determining how a collection of zero or more items is to be presented by the media playback application **400**. The manner in which media consumption manager **410** determines the order in which the items is presented is beyond the scope of this invention. As the media consumption manager drives playback of the playlist it begins by first caching as many of the media files in the playlist as possible. That is, once playback starts, the media consumption manager **410** requests successive files in the playlist "queue" or "cache" themselves for playback so that the next N files are stored in N media cache(s) **402** and ready to play. In one embodiment the actual mechanism of caching a file involves first creating a media consumption process **412** capable of playing the piece of content being cached. The media consumption process **412** contains all of the business rules and other logic necessary to convert audio, video, or still images into a multimedia presentation. After the media consumption process is created and bound to the desired file it requests a media cache **404** to hold the contents of the file to which it is bound. A cache manager **414** is responsive to a request (cache request), as indicated by reference character **416**, from the media consumption component **412**. If cache manager **414** determines that enough memory is available, a media cache **402** is created and returned to the media consumption process. Once created, media cache **402** is configured to automatically begin retrieving the contents of the associated media file from disk memory **208** in either a cooperative or preemptive fashion until its assigned memory partition is used. If cache manager **414** determines there is insufficient memory to hold the cached file, a pending request is created and held by the cache manager **414**. This stops the caching process and determines the number N of files that are currently cached. Once cache manager **414** can no longer cache the next file in the sequence in its entirety, that file and any remaining media files in the playlist that have not been queued, or cached, will only be queued when either no media cache **402** remains in use, the current media cache **402** in use is transitioning to the end of playback in preparation for the next item to play, or in response to a storage active event **318**. (See FIG. **9**). During playback, the media consumption manager **410** sequentially transfers control to the media consumption process **412** as playback continues. Media consumption process **412** retrieves media files from its associated media cache **402** rather than from the disk memory or system memory. As indicated above, the media consumption manager **410** tracks which media files have been processed (e.g., completed playback). After identifying media that has been processed, the media consumption manager **410** releases the media consumption process **412** associated with that piece of media causing the media cache **402** for the media to be released as well.

[**0037**] Media consumption manager **410** and cache manager **414** are configured to respond to event receiver **406** when it retrieves specific events. Event receiver **406** is a component of the media playback application **400** that has registered for memory events **312**, **314**, and **316** sent by system monitor **302** of operating system **216** in multifunction device **100** (See FIG. **3**). In addition event receiver **406** is configured to respond to storage active events **318** if available. As indicated, the term registration is used to describe the concept that event receiver **406** is capable of determining through active or passive manners different operating system states and requesting action on the part of media consumption manager **410** and cache manager **414** to respond to changes in state.

[**0038**] When system requirements change event receiver **406** receives a subsequent memory event **312**, **314**, or **316** indicating that more memory is required by the system to fulfill memory requests to memory manager **304**, and it contacts media consumption manager **410**. Media consumption manager **410** then determines how to remove file data from cache memory **206** to preserve an optimal playback experience. In one embodiment, the media consumption manager starts by removing the last media item in the queue of cached content if more than one item is in the cache. For example, consider a ten (10) megabyte cache memory **206** segmented in two media caches **602**, **604** of five (5) megabytes each. (See FIG. **6**A). Further, consider two media files from a playlist have been cached for playback on the device **100** such that media cache **602** stores a first media file of five (5) megabytes and media cache **604** stores a second media file of five (5) megabytes. Thus, cache memory **206** has no more available storage capacity. Further consider that a GPS program or some other program is executed on the device **100** and requires three (3) megabytes of memory for a mapping operation. If the first media file is currently being retrieved from media cache **602** for playback on the device **100**, the media consumption manager **410** removes the second media file from cache segment **604** to provide storage space for the GPS program (See FIG. **6**B). According to this embodiment, all requests for additional memory first cause the last unplayed file placed in the cache to be removed first. A full file is removed even if the size of the request is less than the total size of the file in the cache. In other words, cache segment **604** now has five (5) megabytes of available storage, as indicated by reference character **608**, which can be used to fulfill the three (3) megabytes requested by the GPS program. Alternatively, when the current media file being processed is the only content remaining in the cache memory, the media consumption component **412** can reduce the size of its cache to provide more memory back to other processes. For example, if the GPS program requires additional cache memory for mapping (e.g., 6.5 megabytes), and the media consumption manager **410** identifies that only one file is playing, instead of removing the file from the cache, it instead requests that media consumption process **412** associated with the file reduce the size of the 5 MB cache **602** by 1.5 MB to provide memory back to the system. The cache determines that the portion of the first media file that has completed playback and removes the processed portion from cache segment **602**.

After 1.5 megabytes of the first media file have been removed from segment **602**, the cache segment **602** has available storage space, as indicated by reference character **610**, which can be used by the GPS program. (See FIG. **6**C). Since it is possible for memory events to occur at any time during playback, there is no guarantee that the currently playing item has completed playback of enough memory to respond to the current request by just throwing out data that has already been used. Under this situation the cache will first try to throw out any memory from data that has been presented and then will begin taking from the end of the cache. For example assume that only 500 KB of the media item had been played. When media cache **602** is requested to reduce its cache by 1.5 MB it will first recognize that it can free 500 KB of data from what has already been played as indicated by reference character **610**. It will then reduce the end of the cache by 1 MB to provide a 1.5 MB to the GPS application, as indicated by reference character **612**. (See FIG. **6**D).

[**0039**] Still referring to FIG. **6**D media cache **602** has now entered into a state where it does not have enough memory to hold all of the contents of the associated media file. Media cache **602** has entered windowed operation mode in which a portion of data starting at or before the current position of playback is held in the cache. As playback advances the definition of the window is moved such that the current position of playback is always within the range of data presented in the window. In the typical case where playback is proceeding, the cache will determine at some point that the window needs to be updated so that playback is not interrupted. Typically this is handled by empirically determining some point near the end of the window which will cause the cache window to be updated after playback has reached this position. In other embodiments data flow analysis may be applied to empirically determine how to keep the cache optimally filled as the contents are being consumed. Windowed cache mode is also employed to support playback of media files or loading of other sequentially accessed data through the cache when the size of the content is too large to fit entirely within available cache memory **206**. Referring to FIG. **6**D consider an alternative scenario for the current state of cache memory **206**. In this scenario a GPS application has already been running and allocated the portion of cache memory referred to at **604**/**608**. A second application, for example an electronic mail application, is also in use and has taken the portion of memory at **610**. Finally a third application, for example a calendaring application, has requested and received the memory at **612**. When the caching application **218** determines that a portion of cache memory is needed in order to play a media file 15 MB in size it discovers that only 3.5 MB of cache memory is currently available. As a result, the cache manager **414** assigns 3.5 MB of cache memory to accommodate caching the 15 MB file and initializes a window at the beginning of the file to hold the first 3.5 MB of data from the media file. As playback reaches a point near the end of the 3.5 MB of data available in the cache, the cache updates the cache window such that it now starts at the current playback position and extends for 3.5 MB from that position. This process repeats until the last 3.5 MB of the file is in the cache window.

[**0040**] In order to achieve savings in battery life by using a content cache as described herein to limit access to a storage device **310** with large power requirements, it is necessary to minimize the need to access the storage device **310**. If the entire content may be stored in cache memory **206**, there is no need to access the storage device **310**. In the event that the cache must operate in windowed mode, the storage device **310** must be accessed periodically to refill the contents of the window. As described above, this typically happens when the access to the content reaches some empirically determined location and the cache window is moved. Because exact user behavior is not predictable, in one embodiment, repopulating the contents of the cache window is delayed until the first time data is required that is within the current cache window but not necessarily available in the cache. Once access to storage device **310** begins it is typically more power efficient to access all data necessary to fill the cache rather than waiting for it to be requested. In an alternative embodiment, it is recognized that the multifunction device **100** is capable of executing many different processes and that processes other than the caching application **218** may need to access the storage device **310**. Referring briefly to FIG. **3**, it is noted that file system manager **308** is capable of using system monitor **302** to send a storage active event **318**. Also, in FIG. **4** it is noted that event receiver **406** of the media playback application **400**, which is an exemplary implementation of caching application **218**, is configured to receive a storage active event **318**. When the event receiver **406** receives the storage active event **318** it notifies any active media cache **402** via the media consumption manager **410** and media consumption process **412** that the storage device **310** is active. If media cache **402** is operating in a windowed mode, the media cache **402** can update the window at this point and fill it in order to maintain optimal power consumption for storage device **310**. In addition, cache manager **414** receives notification of a storage active event **226** from the event receiver **406** and can fulfill any pending cache requests when sufficient cache memory **206** is available.

[**0041**] In the event that no media file is currently being played or when the current media file being played by the media consumption process **412** under the control of media consumption manager **410** has completed playback, it is necessary to transition to the next item in the playlist. Note that in the case where no media file is being played the next item in the playlist is the first item to be played. When this transition occurs, the item that has completed playback is typically released and any assigned media cache **402** releases its memory back to the pool of available cache memory **206**. If the next media file being transitioned to has been assigned a cache by the cache manager **414**, then playback transitions to the associated media consumption process **412** and its accompanying media cache **402**. If, however, the cache manager **414** was unable to fulfill the request because insufficient cache memory **206** was available or because cache manager **414** has not previously been requested to provide a cache for this particular media file, the request is fulfilled immediately. In the event that enough cache memory **206** is available to hold the entire contents of the new item a media cache is created of the appropriate size and assigned to media consumption process **412** for the file. If there is not enough memory **206** available to cache the entire file, a cache window is defined for a media cache **402** and assigned to the media consumption process **412** for the file. In the event that no cache memory **206** is available for fulfilling the cache request alternate methods of playback may be considered including directly accessing the contents of the media file from disk memory **208** regardless of the battery implications of so doing. With regards to refilling the cache after the initial allocation, alternative embodiments may elect to refill a portion of the cache at other events. As indicated some may use a storage active event **318** to trigger cache filling. Other embodiments may elect to monitor the amount of available cache memory **206** and when an appropriate amount of memory has become available begin filling the cache. Still other embodiments may elect to monitor the amount of available memory and if operating in windowed mode elect to increase the size of the media cache **402** to allow a larger window of data from the source to be held in the cache **402**.

[**0042**] Referring now to FIG. **7**, a block diagram illustrates a partionable memory **700** within a portable multifunction computing device **100**. For simplicity the memory **700** is represented as a single block. Notably, in an actual application it may have certain portions reserved for device operation. As this representation is merely illustrative such reserved portions are ignored. As described above in reference to FIG. **2**, program memory **204**, which contains both executable instructions and state data and cache memory **206** are partitions of a larger memory pool such as memory pool **702**. In an environment as described herein, caching application **218** must establish limits on the amount of the memory that can be assigned to a cache. In one embodiment, where the size of the memory pool **702** is known (e.g., memory of a multifunction computing device **100**) it is possible to decide that cache memory **206** will never be allowed to consume more than a fixed percentage of the total memory pool **702**.

[**0043**] An alternative embodiment of cache sizing allows the cache memory **206** to consume as much memory of memory pool **702** as possible. In such an embodiment, when the caching application **218** is the only application in use on device **100**, any memory not required by the operating system **216** can be assigned to the caching application **218** for use as either cache memory or as storage for data and state information. However, when assigning all available memory, it is necessary to first quantify the amount of memory in memory pool **702** that is not already assigned to the operating system **216**. In one embodiment operating system **216** supports a method for determining the amount of available memory which caching application **218** may use to determine how large a partition of memory pool **702** is available for cache memory **206**. An alternative embodiment of caching application **218** leverages the method just described but adds additional logic to guarantee that operating system **206** has enough memory to successfully fulfill requests. Since a multifunction device **100** is by its design extensible to support other functions it is difficult to define or predict how much memory of memory pool **702** will be required to fulfill all of the requests made through operating system **216**. The method described above wherein an amount of available memory is returned is typically an instantaneous snapshot of the available memory and does not take into account the demands that future operations may or may not place on the system. If these future operations require significant amounts of memory from memory pool **702** to complete processing and that memory has already been used by caching application **218** as cache memory **206** there may not be enough memory available. In this scenario, operating system **216** may begin to have undesired and sometimes unpredictable behavior. To make sure that operating system **206** has enough memory to complete its task caching application **218** in addition to using the method for determining the amount of memory instantaneously available, can define two partitions of memory pool **702** to limit the amount of memory that can be used as cache memory **206**.

[**0044**] A reserved partition **704** is a partition of memory pool **702** that caching application **218** reserves for its own operation. This partition is excluded from use as cache memory **206**. In addition the critical partition **706** is reserved by caching application **218** for use by operating system **206**. In an embodiment where the size of memory pool **702** is well defined the size of the reserved and critical partitions may be hard coded into caching application **218**. Alternative embodiments define the size of the critical and reserve partitions by monitoring the amount of available memory as expressed by a method of operating system **206** and defining a set of bounds to establish the limit. For example the lower bound for reserved partition **704** may be 4 MB of free memory while the upper bound is 2 MB of free memory. The lower bound for the critical region is the same as the upper bound for the reserved region, e.g. 2 MB. The upper bound for the critical region is reached when memory pool **702** has been completely allocated or potentially slightly before. Consider the lower and upper bounds of the memory pool in the context of an empty bucket. As memory is allocated water is added to the bucket. When the water (memory) reaches a lower bound of 4 inches (MB) from the top of the bucket the reserved partition has been entered. When it crosses the upper bound of 2 inches (MB) then the reserved partition has been left. Thus, the caching application **218** monitors the amount of free memory and takes action when memory enters the reserved or critical partition. In one embodiment, caching application **218** treats entering the reserved or critical partitions the same as memory full event **314** or memory critical events **316**. The end result is that the amount of memory pool **702** allocated as cache memory **206** is reduced until the caching application **218** determines that all reasonable efforts have been made to free memory back to the system and/or caching application **218** determines that memory usage has exited the critical or reserved partition. Alternative embodiments may simply cancel current operations or change behaviors to try a free memory from cache memory **206**. While the model herein is described in the context of a caching application **218** and an operating system **206** executing on device **100**, it has similar applicability when more applications are executing on device **100**.

[**0045**] Referring now to FIG. **8** an exemplary flow chart illustrates a method for processing a playlist of media files from the cache memory of a device according to one exemplary embodiment of the invention. At **802**, the caching application receives input from a user of the device to begin playback of media items (e.g., media files) included in the playlist. The caching application opens the current item in the playlist at **804**. For example, the caching application opens the first media item in the playlist. At **806**, the caching application attempts to cache the current media file (i.e., the first media file). If the current media file is not cached at **808**, the caching application plays the current item and makes the next media file in the playlist (e.g., the second media file) the current media file at **810** and opens the current item in the playlist at **804**. If the current media file is cached at **808**, the caching application begins playing the current item at **812**. At **814**, the caching application determines the next media file in the playlist to cache. The caching application attempts to cache the next media file at **816**. If the next media file is not cached at **818**, the caching application waits for all cached items to complete playback at **820**. At **822** the caching application makes the first uncached media file in the playlist the current media file and opens the current media file at **804**. If the next media file is cached at **818**, the caching application determines the next media file in the playlist to cache at **814**. The process continues until the next media item can no longer be determined.

[0046] Referring now to FIG. **9**, an exemplary flow chart illustrates a method for caching a piece of media in a cache memory of a device according to one exemplary embodiment of the invention. At **902**, a caching application determines that it has data to cache. For example, the user begins playback of a sequence of tracks and the first item in the playback is being prepared for playback. The caching application determines the amount of cache memory available at **904**. At **906**, the caching application determines if there is enough cache memory available to store the data associated the media file. If the caching application determines there is enough memory available at **906**, the caching application creates a media cache with the correct number of segments to hold the contents of the media file and allocates memory for those segments at **908**. If the caching application determines there is not enough memory available at **906**, the caching application generates a pending cache request at **910**. At **912**, the caching application is responsive to the pending storage request to periodically determine if there is enough cache memory available to store the data associated with the media file or if playback for the specified media file has begun. When the caching application determines that the item must be cached at **912**, the caching application creates a media cache with the correct number of segments and allocates memory for those segments to fill with data from the media file at **908**.

[0047] Referring now to FIG. **10**, an exemplary flow chart illustrates a method for responding to low memory conditions in a device managing media caches according to one exemplary embodiment of the invention. The caching application begins by caching all media files until cache memory is no longer available at **1002**. The caching application waits for a memory event informing the caching application that the system needs more memory at **1004**. At **1006**, the caching application is responsive to the memory event to determine if data associated with more than one media file to be processed on the device is currently stored in cache memory. If the caching application determines that data associated with only one item is currently stored in cache memory at **1006**, the cache size of the current item is reduced at **1008**. For example, if the data is associated with a media file, the number of segments allocated to the media cache is reduced causing the size of the media cache to reduce. If available content that has already been played is removed from the cache, otherwise content that has yet to be played and is found at the end of the cache is removed. If the caching application determines that data associated with more than one media item is currently stored in cache memory at **1006**, the data associated with the last media item stored last in the media cache is removed at **1010**. At **1012**, the caching application determines if it has released enough memory to respond to the request from the operating system at **1012**. If the caching application determines that there is not enough storage space removed from the cache at **1012**, the caching application again determines if more than one item is stored in the media cache at **1006**. If the caching application determines there is enough storage space has been released to fulfill the request at **1012** the caching application return to **1004** to wait for a request for additional memory.

[0048] In operation, computer **130** executes computer-executable instructions such as those illustrated in the FIGS. **8-10** to implement aspects of the invention.

[0049] The order of execution or performance of the operations in embodiments of the invention illustrated and described herein is not essential, unless otherwise specified. That is, the operations may be performed in any order, unless otherwise specified, and embodiments of the invention may include additional or fewer operations than those disclosed herein. For example, it is contemplated that executing or performing a particular operation before, contemporaneously with, or after another operation is within the scope of aspects of the invention.

[0050] Embodiments of the invention may be implemented with computer-executable instructions. The computer-executable instructions may be organized into one or more computer-executable components or modules. Aspects of the invention may be implemented with any number and organization of such components or modules. For example, aspects of the invention are not limited to the specific computer-executable instructions or the specific components or modules illustrated in the figures and described herein. Other embodiments of the invention may include different computer-executable instructions or components having more or less functionality than illustrated and described herein.

[0051] When introducing elements of aspects of the invention or the embodiments thereof, the articles “a,”“an,”“the,” and “said” are intended to mean that there are one or more of the elements. The terms “comprising,”“including,” and “having” are intended to be inclusive and mean that there may be additional elements other than the listed elements.

[0052] As various changes could be made in the above constructions, products, and methods without departing from the scope of aspects of the invention, it is intended that all matter contained in the above description and shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A method of managing memory for optimizing performance of a multifunction portable computing device, said method comprising:

receiving at least one cache request from an application being executed by the computing device, said cache request specifying data to be cached;

defining a memory area of the computing device for caching during execution of the application, said memory area comprising a plurality of segments, said segments each having a storage capacity available for caching;

allocating one or more of the segments for caching the data specified by the cache request; and retrieving cached data from the one or more segments for processing by the application.

2. The method of claim 1 further comprising determining, based on the cache request, whether the computing device has sufficient memory for caching the data specified by the cache request before allocating the one or more segments for caching.

3. The method of claim 2 further includes generating a pending cache request for the data specified by the cache request when the determining indicates the computing device does not have sufficient memory for caching the specified data.

4. The method of claim 3 further comprising monitoring the plurality of segments to identify when at least one of plurality of segments has the sufficient storage capacity available for storing the specified data in response to the pending cache request.

5. The method of claim 1, wherein the receiving includes receiving a memory usage event from one or more different application being executed by the computing device, said memory usage event specifying a current memory state of the computing device and indicating whether additional memory is required by the one or more different applications to perform their operations.

6. The method of claim 5, wherein the received memory usage event is one or more of the following:

a memory need event indicating that the device has reached a state in which requests for large amounts of memory may no longer be fulfilled because memory is not available;

a memory full event indicating that the amount of available memory is not generally sufficient for standard operation; and

a memory critical event indicating the amount of available memory is below a critical threshold level.

7. The method of claim 5 further including adjusting the memory area available for caching, wherein said adjusting includes:

allocating a portion of the memory area back to a memory system of the device when at least two of the plurality of segments are allocated for caching the data specified by the cache request; or

allocating a portion of the memory area back to the memory system of the device when only one of the plurality of segments is allocated for caching the data specified by the cache request.

8. The method of claim 1, wherein the storage capacity of each of the plurality of segments is fixed, and wherein the number of segments in the plurality of segments is determined by the amount of memory requested by the cache request.

9. The method of claim 8, wherein the allocating includes allocating a different one or more of the segments for caching the different data specified by the cache request when the determining indicates the computing device has sufficient memory available for caching the different data.

10. The method of claim 8 further comprising identifying one or more of the plurality of segments caching data specified by the cache request that is not currently being processed by the application, and reallocating the identified one or more of the segments for caching the different data specified by the subsequent cache request when the determining indicates the computing device has sufficient memory available for caching the different data.

11. The method of claim 1 further comprising monitoring the plurality of segments to identify one or more of the plurality of segments caching the data that has been processed by the application, and removing the processed data from the identified one or more segments.

12. One or more computer-readable media having computer executable components executed by a multifunction portable computing device for optimizing performance of the portable computing device, said computer-readable media comprising:

a defining component for defining a memory area of the computing device for caching during execution of the application, said memory area comprising a plurality of segments, said segments each having a predetermined storage capacity available for caching;

a cache management component for receiving at least one cache request from an application being executed by the computing device, said cache request specifying data to be cached, and said a cache management component determining, based on the cache request, whether the computing device has sufficient memory for caching the specified data; and

a consumption component for allocating one or more of the segments for caching the specified data when the computing device is determined to have sufficient memory for caching the data specified by the cache request.

13. The computer-readable media of claim 12, wherein the cache management component is further configured for generating a pending cache request for the specified data when the cache management component indicates the computing device does not have sufficient memory for caching the specified data.

14. The computer-readable media of claim 12, wherein the cache management component is configured for receiving at least one subsequent cache request, said subsequent cache request specifying different data to be cached, and wherein the cache management component is further configured for determining, based on the subsequent cache request, whether the computing device has sufficient memory available for caching the different specified data.

15. The computer-readable media of claim 14, wherein the consumption component is configured for allocating a different one or more of the segments for caching the different specified data when the cache management component indicates the computing device has sufficient memory available for caching the different specified data.

16. The computer-readable media of claim 14, wherein consumption component is further configured for:

retrieving cached data from the one or more segments for processing by the application;

identifying one or more of the plurality of segments caching data that is not currently being processed by the application; and

reallocating the identified one or more of the segments for caching the different specified data when the determining indicates the computing device has sufficient memory available for caching the different specified data.

17. The computer-readable media of claim 16, wherein the consumption component is further configured for monitoring the plurality of segments to identify one or more of the plurality of segments caching data that has been processed by the application and removing the processed data from the identified one or more segments.

18. A portable computing device comprising:

an user interface, associated with the portable computing device, for generating a cache request in response to input from a user, said cache request specifying data to be cached;

a processor, associated with the portable computing device, for executing computer-executable instructions for:

defining a memory area of the computing device for caching during execution of the application, said memory area comprising a plurality of segments, said segments each having a predetermined storage capacity available for caching;

determining, based on the cache request, whether the computing device has sufficient memory for caching the specified data before allocating the one or more segments for caching;

allocating one or more of the segments for caching the specified data when the computing device is determined to have sufficient memory for caching the data specified by the cache request; and

retrieving cached data from the one or more segments for processing by the application.

19. The device of claim 18, wherein the processor further executes computer-executable instructions for:

monitoring the plurality of segments to identify one or more of the plurality of segments caching data that has been processed by the application; and

removing the processed data from the identified one or more segments.

20. The device of claim 18, wherein defining a memory area further includes partitioning a memory area into a caching memory portion, a reserve memory portion, and a critical memory portion, wherein the caching memory portion has a predetermined storage capacity available for caching, and wherein the reserve memory portion has a predetermined storage capacity available for additional caching, and wherein the critical memory portion has a predetermined storage capacity available for supporting an operating system executing on the portable computing device, and wherein at least a portion of the storage capacity of the reserve memory portion is allocated to the critical memory portion during a memory critical event

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