Technical Brief

Managed Flash Background Operations Series

Part 4: Understanding Garbage Collection in NAND Flash Memory

NAND flash memory has many data storage benefits and is a primary choice for applications where high speed data transfer, high reliability and low power consumption are required. There are capabilities within managed flash devices that help it to operate efficiently, such as garbage collection (GC). As data cannot be overwritten in NAND flash memory until associated flash cells are emptied first, GC is the capability that addresses this limitation and a process that needs to be performed regularly. This technical brief presents garbage collection and its capabilities within NAND flash memory and is the fourth installment in the Managed Flash Background Operations Series.

Garbage Collection Overview

When a smartphone is used for different applications, the user will save new data and erase data that is no longer needed (such as pictures, phone numbers, text messages, voice mails, browse data, meta data, cookies, etc.). The erased data is not visible to the user (in folders) and may appear to be removed from the phone, but, in actuality, it may still be physically present. Under this scenario, how can storage space be freed up if the erased data still exists in flash cells?

As their name implies, smartphones are smart. After a user erases data, the smartphone understands that this data is not needed and communicates with the managed flash device[1] that the data is invalid. In turn, the managed flash device runs garbage collection at convenient times, collecting invalid data[2] and physically erasing them from flash memory cells. The GC process starts by segregating valid data[3] from invalid data. Once all of the invalid data is collected, the managed flash device physically erases it from flash memory cells and the physical space is now available for storing new data.

Why is Garbage Collection Needed?

Managed flash devices need to physically erase old data before writing new data on a flash cell – this requires an additional area for the erase circuitry that needs to be economized while still making sure that erase times are shortened. In order to erase flash cells in a timely manner, garbage collection is required.

Garbage collection is not a simple single-step erase process. There are multiple steps such as separating valid data from the invalid data mixed in one physical block[4], reprogramming the new data into a new block space location within the same flash die, collecting all of the invalid data and physically erasing them. Digging deeper, all valid data is copied to a new physical block, and upon completion, the original data in the old block is marked as invalid data, and that data in the physical block is erased.

As depicted in Figure 1, a NAND flash memory die is divided into several blocks where flash cells are being filled with valid data. Over time, the valid data may become unneeded and turned into invalid data.

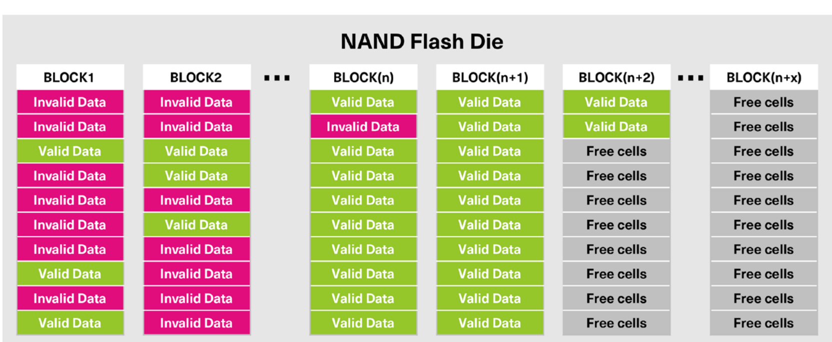

Figure 1: Example of a NAND flash memory die divided into physical blocks that hold valid and invalid data.

The Garbage Collection Process

A managed flash device runs the GC process when it sees the need to free up flash memory space. The managed flash device selects a target block and maps data to it. If the block has a mixture of valid and invalid data, the device will separate and identify valid data from invalid data. After this separation, valid data is transferred to a new data space in flash memory and is stored. After changing all of the data in the block to invalid data, the entire block is erased and is now available to save new data as showcased in Figure 2.

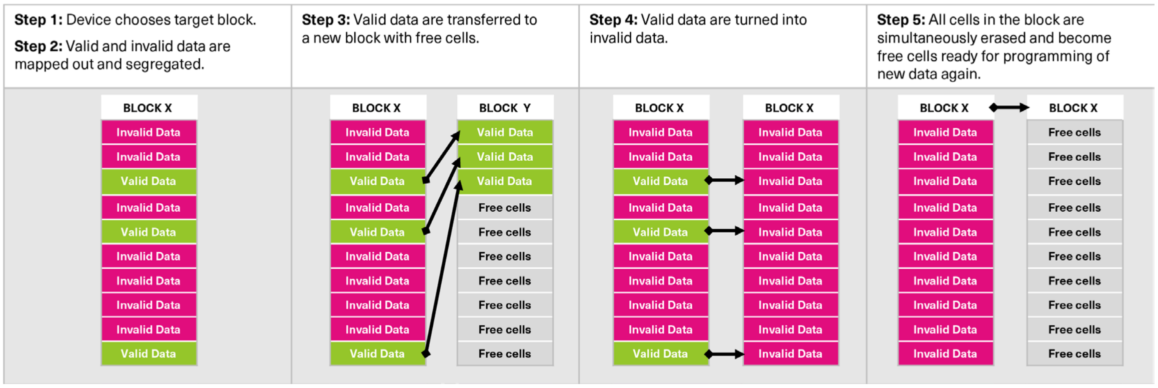

Figure 2: Example of garbage collection process in a managed flash device.

How to Optimize Garbage Collection?

The garbage collection process cleverly addresses one of the challenges that managed flash devices face in recovering data space. However, the process is not without side effects. For example, garbage collection involves erasing and writing data which induces wear and tear on a managed flash device and shortens its lifespan. To make sure that invalid data is removed and free space is available to write new data in a timely manner, the GC process requires optimal timing for execution.

The GC process also affects device performance. An objective of garbage collection is to minimize the amount of valid data that needs to be transferred to a new location. When more data is moved during the GC process, incoming data to the managed flash device may need to wait longer until the GC process completes. In this instance, device bandwidth is temporarily reduced and can be reflected in device performance. Thus, the ideal scenario is to not mix valid data and invalid data in the same block.

When valid and invalid data is not mixed in the same block (or minimally mixed), the block is considered 'Clean State.' Conversely, a high level of valid and invalid data mixed in the same block is considered 'Dirty State.' The contrast between the two states is illustrated in Figure 3. In Clean State, blocks 3 and 4 have minimal valid data and would be good targets for garbage collection. When the managed flash device is in a Dirty State, it will not matter which block that the managed flash device chooses to target since a significant amount of the valid data will need to be relocated. This scenario can have an adverse effect on device performance.

The GC process works optimally when managed flash devices are as clean as possible, which lends to the next step as to how to keep devices clean. A simple way for the host controller to keep devices clean is to remove, or unmap, invalid data in a timely manner. Unmapping allows the host controller to inform the managed flash device as to which data can be turned into invalid data. When invalid data is unmapped in a timely manner, relocation of unnecessary but still valid data can be minimized.

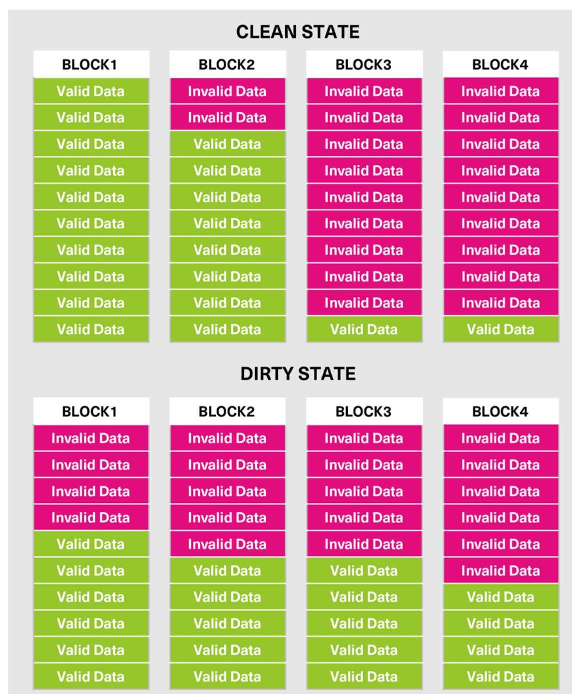

Figure 3: Example of the difference between Clean State and Dirty State.

Summary

Managed flash devices have finite capacities for data storage. When data is erased from these devices, the data is not immediately erased, but instead, is marked as invalid. Therefore, it is crucial to free up physical data space by removing invalid data in a timely manner. To address this objective, garbage collection is a very important process for managed flash devices and is used to recover physical storage space for storing new data. The GC process reprograms valid data into a new block space location within the same NAND flash memory die and erases all data in the old block simultaneously. As the GC process involves erasing and writing which can affect the managed flash device's lifetime, it is important to optimize the GC process algorithm. To minimize performance effects, it is also important to keep the managed flash device in a Clean State.

The next brief in the Managed Flash Background Operations Series covers logical to physical address translation, which is a process used by managed flash devices to assign and locate data within the NAND die.

FOOTNOTES:

[1] A managed flash device combines raw NAND flash memory and an intelligent controller in one integrated package, enabling memory management to be performed internally.

[2] Data considered invalid is no longer of use and may be removed from the managed flash device.

[3] Data considered valid (or 'still-needed' data) needs to be stored in the managed flash device.

[4] A physical block is a collection of flash memory cells that are electrically connected to erase simultaneously.