



VMware Virtual Disks

Virtual Disk Format 1.0

Virtual machines created with VMware products typically use virtual disks. The virtual disks, stored as files on the host computer or on a remote storage device, appear to the guest operating systems as standard disk drives.

This technical note begins with a high-level introduction to the layout of the files that make up a VMware virtual disk of the type used by VMware Workstation 4, VMware Workstation 5, VMware Player, VMware GSX Server 3, VMware Server, and VMware ESX Server 3. It then drills down into the details of the data structures inside those virtual disk files.

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Virtual machines created by VMware products other than VMware Workstation 4, VMware Workstation 5, VMware GSX Server 3, and VMware ESX Server 3 may use formats different from

VMware, Inc. 3145 Porter Drive Palo Alto, CA 94304 www.vmware.com

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those described in this document. Key areas that are not discussed in this technical note include the following:

- Virtual disks created in legacy mode in Workstation 5, or virtual disks created in ESX Server 2 or earlier, GSX Server 3 or earlier, Workstation 4 or earlier, or VMware ACE
- Device-backed virtual disks
- Encryption
 - Encrypted extents
 - Encrypted descriptor files
- Defragmenting a virtual disk
- Shrinking a virtual disk
- Consolidating virtual disks

Layout Basics

VMware virtual disks can be described at a high level by looking at two key characteristics.

- The virtual disk may use backing storage contained in a single file, or it may use storage that consists of a collection of smaller files.
- All of the disk space needed for a virtual disk's files may be allocated at the time the virtual disk is created, or the virtual disk may start small and grow only as needed to accommodate new data.

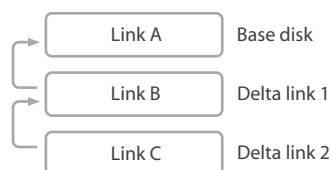
A particular virtual disk may have any combination of these two characteristics.

One common characteristic of recent-generation VMware virtual disks is that a text descriptor describes the layout of the data in the virtual disk. This descriptor may be saved as a separate file or may be embedded in a file that is part of a virtual disk. The section titled [The Descriptor File on page 3](#) explains the information contained in the descriptor.

The way a virtual disk uses storage space on a physical disk varies, depending on the type of virtual disk you select when you create the virtual machine.

Initially, for example, a virtual disk consists of only the base disk. If you take a snapshot of a virtual machine, its virtual disk includes both the base link and a delta link (referred to in some product documentation as a redo-log file). Changes the guest operating system has written to disk since you took the snapshot are stored in the delta link. It is possible for more than one delta link to be associated with a particular base disk.

Think of the base disk and the delta links as links in a chain. The virtual disk consists of all the links in the chain.



Links in the chain that makes up the virtual disk



Each link in the chain is made up of one or more extents.



Extents that make up a link

An extent is a region of physical storage, often a file, that is used by the virtual disk.

In the links diagram above, links B and C are necessarily made up of extents that begin small and grow over time, referred to as sparse extents. Link A can be made up of extents of any kind — sparse, preallocated, or even backed directly by a physical device.

The Descriptor File

For a more detailed view of how these elements of a virtual disk come together in practice, look at the following example text descriptor file, called `test.vmdk`. It describes a link in a virtual disk that is split into files no larger than 2GB each and that starts small and grows as data is added. The descriptor file is not case-sensitive.

Lines beginning with `#` are comments and are ignored by the VMware program that opens the disk.

```
% cat test.vmdk
# Disk DescriptorFile
version=1
CID=fffffffe
parentCID=fffffffe
createType="twoGbMaxExtentSparse"

# Extent description
RW 4192256 SPARSE "test-s001.vmdk"
RW 4192256 SPARSE "test-s002.vmdk"
RW 2101248 SPARSE "test-s003.vmdk"

# The Disk Data Base
#DDB
ddb.adapterType = "ide"
ddb.geometry.sectors = "63"
ddb.geometry.heads = "16"
ddb.geometry.cylinders = "10402"
```

The Header

The first section of the descriptor is the header. It provides the following information about the virtual disk:

- **version**
The number following `version` is the version number of the descriptor. The default value is 1.
- **CID**
This line shows the content ID. It is a random 32-bit value updated on the first write every time the virtual disk is opened.

Every link header contains both a content ID and a parent content ID (described below).

If a link has a parent — as is true of links B and C in the diagram of links in a chain — the parent content ID is the content ID of the parent link.



If a link has no parent — as is true of link A in the diagram of links in a chain — the parent content ID is set to `CID_NOPARENT` (defined below).

The purpose of the content ID is to check the following:

- In the case of a base disk with a delta link, that the parent link has not changed since the time the delta link was created. If the parent link has changed, the delta link must be invalidated.
- That the bottom-most link was not modified between the time the virtual machine was suspended and the time it was resumed or between the time you took a snapshot of the virtual machine and the time you reverted to the snapshot.
- `parentCID`
This line shows the content ID of the parent link — the previous link in the chain — if there is one. If the link does not have any parent (in other words, if the link is a base disk), the parent's content ID is set to the following value:

```
#define CID_NOPARENT          (~0x0)
```

- `createType`
This line describes the type of the virtual disk. It can be one of the following:

- `monolithicSparse`
- `vmfsSparse`
- `monolithicFlat`
- `vmfs`
- `twoGbMaxExtentSparse`
- `twoGbMaxExtentFlat`
- `fullDevice`
- `vmfsRaw`
- `partitionedDevice`
- `vmfsRawDeviceMap`
- `vmfsPassthroughRawDeviceMap`

The first six terms are used to describe various types of virtual disks. Terms that include `monolithic` indicate that the data storage for the virtual disk is contained in a single file. Terms that include `twoGbMaxExtent` indicate that the data storage for the virtual disk consists of a collection of smaller files. Terms that include `sparse` indicate that the virtual disks start small and grow to accommodate data. Some product documentation refers to these virtual disks as growable disks. Terms that include `flat` indicate that all space needed for the virtual disks is allocated at the time they are created. Some product documentation refers to these virtual disks as preallocated disks.

Terms that include `vmfs` indicate that the disk is an ESX Server disk.

The terms `fullDevice`, `vmfsRaw`, and `partitionedDevice` are used when the virtual machine is configured to make direct use of a physical disk — either a full disk or partitions on a disk — rather than store data in files managed by the host operating system.

The terms `vmfsRawDeviceMap` and `vmfsPassthroughRawDeviceMap` are used in headers for disks that use ESX Server raw device mapping.



- `parentFileNameHint`

This line, present only if the link is a delta link, contains the path to the parent of the delta link.

The Extents

Each line of the second section describes one extent. The extents are enumerated beginning with the one accessible at offset 0 from the virtual machine's point of view. The format of the line looks like one of the following examples:

```

RW 4192256 SPARSE "test-s001.vmdk"
  ↓         ↓         ↓
Access      Size in sectors  Type of extent  Filename

RW 1048576 FLAT "test-f001.vmdk" 0
  ↓         ↓         ↓         ↓
Access      Size in sectors  Type of extent  Filename  Offset

```

The extent descriptions provide the following key information:

- Access — may be `RW`, `RDONLY`, or `NOACCESS`
- Size in sectors — a sector is 512 bytes
- Type of extent — may be `FLAT`, `SPARSE`, `ZERO`, `VMFS`, `VMFSSPARSE`, `VMFSRDM`, or `VMFSRAW`.
- Filename — shows the path to the extent (relative to the location of the descriptor)

Note: If the type of the virtual disk, shown in the header, is `fullDevice` or `partitionedDevice`, then the filename should point to an IDE or SCSI block device. If the type of the virtual disk is `vmfsRaw`, the filename should point to a file in `/vmfs/devices/disks/`.

- Offset — the offset value is specified only for flat extents and corresponds to the offset in the file or device where the guest operating system's data is located. For preallocated virtual disks, this number is zero. For device-backed virtual disks (physical or raw disks), it may be non-zero.

The Disk Database

Additional information about the virtual disk is stored in the disk database section of the descriptor. Each line corresponds to one entry. Each entry is formatted as follows:

```
ddb.<nameOfEntry> = "<value of entry>"
```

When the virtual disk is created, the disk database is populated with entries like those shown in the example descriptor. The entry names are self-explanatory and show the following information:

- The adapter type can be `ide`, `buslogic`, `lsilogic`, or `legacyESX`. The `buslogic` and `lsilogic` values are for SCSI disks and show which virtual SCSI adapter is configured for the virtual machine. The `legacyESX` value is for older ESX Server virtual machines when the adapter type used in creating the virtual machine is not known.
- The geometry values — for cylinders, heads, and sectors — are initialized with the geometry of the disk, which depends on the adapter type.



There is one descriptor, and thus one disk database, for each link in a chain. Searches for disk database information begin in the descriptor for the bottom link of the chain — Link C in the illustration of links in the chain — and work their way up the chain until the information is found.

Layout of the Example Disk

The link described in the example descriptor has three extents, each of which is a file on disk. The following diagram shows the layout of this link and the filenames of the extents:



Simple Extents

The simplest kinds of extents are backed by a region of a file or a block device. These include the extent types shown in the descriptor as `FLAT`, `VMFS`, `VMFSRDM`, or `VMFSRAW`.

Note: A virtual disk described as monolithic and flat consists of two files. One file contains the descriptor. The other file is the extent used to store virtual machine data.

Consider an extent that is described by the following line in a descriptor file:

```
RW 1048576 FLAT "test-f001.vmdk" 0
```

This means that the file `test-f001.vmdk` is $1048576 \text{ sectors} \times 512 \text{ bytes/sector} = 536870912 \text{ bytes} = 512\text{MB}$ in size.

Note: In VMware ESX Server, each link includes only one extent.

Accessing a Sector in a Flat Extent

Assume you want access to data in a link that is made up of two flat extents. The size of the first extent is $C1$. The size of the second extent is $C2$. You want access to sector x in the virtual disk, and x' is the sector offset in extent 1 or 2 where x is located.

- If $x \geq C1$, the sector is in extent2. Its relative sector offset is $x' = x - C1$
- If $x < C1$, the sector is in extent1 at offset x .
 $x' = x$

Hosted Sparse Extents

In a sparse extent, data storage space is not allocated in advance. Instead, space is allocated as it is needed. A sparse extent also keeps track of whether or not data is represented in the extent. Delta links made up of sparse extents use the copy-on-write semantic.



Each sparse extent is made up of the following blocks:

Sparse header	
Embedded descriptor	(Optional)
Redundant grain directory	
Redundant grain table #0	
...	
Redundant grain table #n	
Grain directory	
Grain table #0	
...	
Grain table #n	
(Padding to grain align)	
Grain	
Grain	
...	

Hosted Sparse Extent Header

The following example shows the content of a sparse extent's header from a VMware hosted product, such as VMware Workstation, VMware Player, VMware ACE, VMware Server, or VMware GSX Server:

```
typedef uint64 SectorType;
typedef uint8 Bool;

typedef struct SparseExtentHeader {
    uint32    magicNumber;
    uint32    version;
    uint32    flags;
    SectorType capacity;
    SectorType grainSize;
    SectorType descriptorOffset;
    SectorType descriptorSize;
    uint32    numGTEsPerGT;
    SectorType rgdOffset;
    SectorType gdOffset;
    SectorType overHead;
    Bool      uncleanShutdown;
    char      singleEndLineChar;
    char      nonEndLineChar;
    char      doubleEndLineChar1;
    char      doubleEndLineChar2;
    uint8     pad[435];
} SparseExtentHeader;
```

This structure needs to be packed. If you use gcc to compile your application, you must use the keyword `__attribute__((__packed__))`.



Notes

- All the quantities defined as `SectorType` are in sector units.
- `magicNumber` is initialized with

```
#define SPARSE_MAGICNUMBER 0x564d444b /* 'V' 'M' 'D' 'K' */
```

 This magic number is used to verify the validity of each sparse extent when the extent is opened.
- `version`
 The value of this entry should be 1.
- `flags` contains the following two bits of information in the current version of the sparse format:
 - bit 0: valid new line detection test
 - bit 1: redundant grain table will be used
- `grainSize` is the size of a grain in sectors. It must be a power of 2 and must be greater than 8 (4KB).
- `capacity` is the capacity of this extent in sectors — always a multiple of the grain size.
- `descriptorOffset` is the offset of the embedded descriptor in the extent. It is expressed in sectors. If the descriptor is not embedded, all the extents in the link have the descriptor offset field set to 0.
- `descriptorSize` is valid only if `descriptorOffset` is non-zero. It is expressed in sectors.
- `numGTesPerGT` is the number of entries in a grain table. The value of this entry for VMware virtual disks is 512.
- `rgdOffset` points to the redundant level 0 of metadata. It is expressed in sectors.
- `gdOffset` points to the level 0 of metadata. It is expressed in sectors.
- `overHead` is the number of sectors occupied by the metadata.
- `uncleanShutdown` is set to `FALSE` when VMware software closes an extent. After an extent has been opened, VMware software checks for the value of `uncleanShutdown`. If it is `TRUE`, the disk is automatically checked for consistency. `uncleanShutdown` is set to `TRUE` after this check has been performed. Thus, if the software crashes before the extent is closed, this boolean is found to be set to `TRUE` the next time the virtual machine is powered on.
- Four entries are used to detect when an extent file has been corrupted by transferring it using FTP in text mode. The entries should be initialized with the following values:

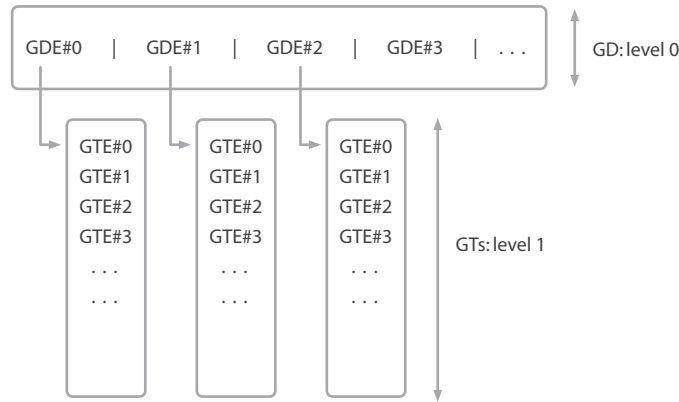

```
singleEndLineChar = '\n';
nonEndLineChar = ' ';
doubleEndLineChar1 = '\r';
doubleEndLineChar2 = '\n';
```

Hosted Sparse Extent Metadata

There are two levels of metadata in a sparse extent from a hosted VMware product. Level-0 metadata is called a grain directory or a GD. Level-1 metadata is called a grain table or a GT. Each



entry in the level-0 metadata points to a block of level-1 metadata, as shown in the following diagram:



Redundancy

VMware software keeps two copies of the grain directories and grain tables on disk to improve the virtual disk's resilience to host drive corruption.

Grain Directory

Each entry in a grain directory is called a grain directory entry or GDE. A grain directory entry is the offset in sectors of a grain table in a sparse extent. The number of grain directory entries per grain directory (the size of the grain directory) depends on the length of the extent. A grain directory entry is a 32-bit quantity.

Grain Table

Each entry in a grain table is called a grain table entry or GTE. A grain table entry points to the offset of a grain in the sparse extent. There are always 512 entries in a grain table, and a grain table entry is a 32-bit quantity. Consequently, each grain table is 2KB.

In a newly created sparse extent, all the grain table entries are initialized to 0, meaning that the grain to which each grain table entry points is not yet allocated. Once a grain is created, the corresponding grain table entry is initialized with the offset of the grain in the sparse extent in sectors.

Note: All the grain tables are created when the sparse extent is created, hence the grain directory is technically not necessary but has been kept for legacy reasons. If you disregard the abstraction provided by the grain directory, you can redefine grain tables as blocks of grain table entries of arbitrary size. If there were no grain directories, there would be no need to impose a length of 512 entries.

Grain

A grain is a block of sectors containing data for the virtual disk. The granularity is the size of a grain in sectors. It is a property of the extent and is specified in the sparse extent header as `grainSize`. The default is currently 128, thus each grain contains 64KB of virtual machine data. The size of a sparse extent should be a multiple of `grainSize`.

Accessing a Sector in a Hosted Sparse Extent

Assume you want access to data in sector `x` stored in a link containing a single sparse extent. You need to locate the grain containing this sector (if it exists) by first looking up the grain directory entry to find the location of the grain table that records the grain's location.



The area accessible with a single grain table is

$$\begin{aligned}
 \text{gtCoverage} &= \text{number of GTEs per GT} \times \text{grainSize} \\
 &= 512 \times 128 \\
 &= 2^G \times 2^7 \\
 &= 2^{16} \text{ sectors} \\
 &= 32\text{MB}
 \end{aligned}$$

If grainSize is defined as

$$\text{grainSize} = 2^G \text{ bytes}$$

then

$$\text{gtCoverage} = 2^{(9+G)} \text{ sectors}$$

To verify that the grain containing the sector you are interested in has been allocated, you must examine a grain table. To find the grain table you need to use, examine the grain directory entry at offset $E(x/\text{gtCoverage})$ in the grain directory.

$$\text{GDE} = \text{GD}[\text{floor}(x/\text{gtCoverage})]$$

Function floor is defined as: floor(s) is an integer such that

$$\text{floor}(s) \leq s < \text{floor}(s) + 1$$

Using this grain directory entry, you can locate the grain table. The grain you want is pointed to by

$$\text{GTE} = \text{GT}[\text{floor}(x \% \text{gtCoverage}) / \text{grainSize}]$$

If GTE is 0, that means the grain is not yet allocated. All the reads in this grain return sectors of 0s (unless there is a parent link). The first write allocates a grain. If there is no parent, the grain is initialized with 0s. If there is a parent link, you need to respect the copy-on-write semantic and initialize the content of the grain by reading from the parent.

Summary

- $\text{GDE} = \text{GD}[\text{floor}(x / 2^{(9+G)})]$
- $\text{GTE} = \text{GT}[\text{floor}((x \% 2^{(9+G)}) / 2^G)]$
- $[\text{GTE} == 0] \iff [\text{grain is not present, thus}$
 reads with no parent: return 0s;
 reads with a parent: read from parent;
 writes: allocate a grain and write to it]
- $[\text{GTE} != 0] \iff [\text{grain is present, read from and write to it}]$

ESX Server Sparse Extents

Sparse extents in ESX Server have a different layout from those in the hosted products. The sparse extent header in ESX Server refers to the sparse extent as a COW (copy-on- write) disk.

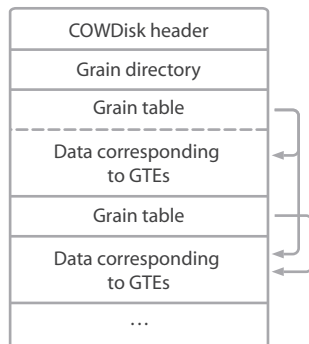
There are two levels of metadata in a sparse extent from VMware ESX Server. The first level, or the grain directory, refers to the set of grain directory entries (GDEs), where each GDE covers $\text{COW_NUM_LEAF_ENTRIES} (=4096) * \text{granularity} (=512 \text{ bytes}) = 2\text{MB}$ of data. The grain directory is stored after the COWDisk header and is updated when a new GDE is initialized or modified.



The second level in the copy-on-write metadata is a grain table (GT). The grain table is 16KB in size and covers 4096 data sectors. A new GT is allocated when a new GDE is added and is modified when a new GTE is allocated.

A GT is followed by the data sectors corresponding to its GTEs. Since delta links (sometimes referred to as redo logs files) are sparse, all the data sectors are not allocated immediately after a GT.

The following diagram illustrates this layout:



ESX Server Sparse Extent Header

The following example shows the content of a sparse extent's header from VMwareESX Server:

```

typedef struct COWDisk_Header {
    uint32    magicNumber;
    uint32    version;
    uint32    flags;
    uint32    numSectors; /* Total sectors in disk */
    uint32    grainSize; /* Size of data pointed to by
                          GTEs */
    uint32    gdOffset; /* Start of GD in COW file, in
                        sectors */

    uint32    numGDEntries; /* # of GDEs to cover numSectors*/
    uint32    freeSector; /* Next free sector in COW file,
                          but file length is real truth.
                          */

    union {
        struct {
            uint32    cylinders;
            uint32    heads;
            uint32    sectors;
        } root;
        struct {
            char       parentFileName[COWDISK_MAX_PARENT_FILELEN];
            uint32     parentGeneration;
        } child;
    } u;
    uint32    generation; /* Generation - not used */
    char      name[COWDISK_MAX_NAME_LEN];
    char      description[COWDISK_MAX_DESC_LEN];
    uint32    savedGeneration; /* Generation when clean -
                              added for 1.1*/

```



```

        char            reserved[8]; // used to be drivetype.
        /* Padding so header is integral number of sectors */
        uint32          uncleanShutdown;
        char            padding[396];
    } COWDisk_Header;

```

Notes

- `magicNumber` is set to `0x44574f43` which is ASCII COWD.
- `version`
The value of this entry should be 1.
- `flags` is set to 3.
- `numSectors` refers to total number of sectors on the base disk.
- `grainSize` refers to the granularity of data stored in delta links, which is one sector by default. Can vary from one sector to 1MB.
- `gdOffset` starts at the fourth sector, as the `COWDisk_Header` takes four sectors.
- `numGDEntries` is `CEIL(numSectors, leafCoverage)`
- `freeSector` is the next free data sector. This needs to be less than the length of the delta link. It is initially set to `gdOffset + numGD Sectors;`
- `savedGeneration` is used to detect the unclean shutdown of the delta link. It is Initially set to 0 by `diskLib`.
- `uncleanShutDown` is used to trigger the copy-on-write metadata check in case there is an unclean shutdown of the delta link.
- The remaining fields are not used. They are present to maintain compatibility with legacy virtual disk formats.

ESX Server Sparse Extent Metadata

The metadata for an ESX Server sparse extent is similar to that for a sparse extent in a hosted VMware product, as described in [Hosted Sparse Extent Metadata on page 8](#), with the following exceptions:

- ESX sparse extents do not include redundant copies of the grain directory.
- Grain tables have 4096 entries.
- Each grain contains 512 bytes.

Accessing a Sector in an ESX Server Sparse Extent

The method for accessing a sector in an ESX Server sparse extent is similar to that described in [Accessing a Sector in a Hosted Sparse Extent on page 9](#). Be sure to allow for the differences in metadata described in [ESX Server Sparse Extent Metadata](#) above.



Glossary

The following terms are used in describing VMware virtual disks.

Chain — A collection of disk links that can be accessed as a single entity.

Child disk — A disk link in a disk chain that has a parent link.

Delta link — A link made of one or more sparse extents. It is a difference link, a child of a parent link. It contains only data that the guest operating system has written to the disk after the creation of the delta link. It allows VMware software to go back in time and restore the content of the disk to the state that existed immediately before the creation of the delta link by simply removing the delta link. Some product documentation refers to delta links as redo-log files.

Descriptor — The data about the disk abstraction such as total space or an extent list. The descriptor may be in a separate file or embedded in the header of a sparse extent. An embedded disk descriptor is embedded into the first extent of a disk link rather than put in a separate disk descriptor file. An embedded disk descriptor can be used only when the first extent of a link is sparse.

Disk — A disk chain that appears to the guest operating system to be a single physical disk.

Disk database — A name-value pair text database found in the disk descriptor. The disk database contains information that the disk library does not need for functionality. Examples of these kinds of values are virtual hardware version and VMware Tools version.

Extent — A region of a disk link backed by a region of a file or device. An extent can be sparse, flat, or device. An extent does not have notions of disk properties but acts purely as storage of a certain size. A flat extent is an extent backed by a flat file. Flat extents are sometimes referred to as plain or preallocated. A sparse extent is an extent that does not allocate its data storage space in advance, but allocates as it goes along. A sparse extent also keeps track of whether or not data is represented in the extent. Sparse extents are sometimes referred to as growable.

Grain — A block of sectors containing data for the virtual machine's disk. Granularity defines the size of a grain. Each grain table entry points to one grain.

Granularity — The size of a single grain in a sparse extent.

Grain directory — Metadata identifying the locations of grain tables. It is ignored by more recent VMware programs because the grain table is allocated in advance.

Grain table — Metadata identifying the locations of grains.

Link — A single node in a disk chain. A link consists of one or more extents.

Parent link — A link that has a child. A parent may also have a parent itself.