jMeta 0.5
Design

Version: 0.2
Status: - Draft -

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1. Introduction

This document specifies the technical design of jMeta 0.5.

Part I.

Requirements

This chapter defines the most important functional and non-functional requirements for `jMeta`. Most relevant input is the document [MetaComp].

2. Scope

2.1. In Scope

`jMeta` is a Java library for reading and writing container and metadata formats. `jMeta` has the following goals:

- Define a robust, easy to use and generic API for reading and writing multimedia (i.e. audio, video and image) metadata

- In addition, define a way to also parse and change typical container formats that embed or surround multimedia metadata

- Be easily extensible with additional metadata or container formats, also by third party

Thus, clearly, `jMeta` targets applications and users in the multimedia editing area, e.g. software to manage an audio, video or image collection.

Special strenght of the library should be its versatility (in a sense of supported formats and generality) as well as its extensibility. At the same time, it targets to offer access to ALL features of each specific format, even the low-level ones, and thus does not want to hide anything from expert users who need fine-grained control.

Using `jMeta`, an application is allowed to access metadata quite generically and comfortably, or it can also explore deep specifics of each format down to the bit and byte level.

2.2. Out of Scope

Metadata not in the audio, video or image domain are not directly in scope of `jMeta` and thus the library might not offer the right abstractions for those. However, it is at least likely that other binary or textual formats can also be parsed quite the same way using `jMeta`.

Furthermore, `jMeta` clearly is no encoding or decoding library, it cannot understand codecs. It might however help to encode or decode by providing access to the low-level details of the container formats. It might be used as basis for extensible encoders or decoders, however, not exactly in high-performance areas where speed is of most importance.

Further things out of scope of specific versions are treated in "4 Requirements and Exclusions".

2.3. Features of version 0.5

Here we give a brief overview of the features the library needs to offer in version 0.5. It is the first version of the library, so its goal is the bare minimum: Implement all core features and support some of the most important data formats. Image and video formats are not yet in scope of this version.

2.3.1. Supported Platforms

In general, `jMeta` in its current version 0.5 can be used with any platform that also supports Java SE in Java SE 9. However, it needs to be specified for which platforms tests were run explicitly and thus it is proven that specific features work on these platforms. We target to support the following platforms like this:

- Windows 10

- Ubuntu 16.04

2.3.2. Supported Metadata Formats

This version adds support for the following audio metadata formats:

- ID3v1 and ID3v1.1

- ID3v2.3

- APEv2

- Lyrics3v2

2.3.3. Supported Container Formate

This version adds support for the following audio container formats:

- MPEG-1 Audio Layer 3 (MP3)

2.3.4. Supported Input Media

This version adds support for the following data sources for reading data:

- Files

- Java `InputStream`s

- Java byte arrays

2.3.5. Supported Output Media

This version adds support for the following output media for writing data:

- Files

- Java byte arrays

2.4. Related Libraries

Here, related Java libraries are treated that are related to what `jMeta` offers. This includes existing productive Java libraries in the area of multimedia, which can be considered as open source competitors to `jMeta` on the one hand, on the other hand, they provide inspiration, possible reuse and also warning examples how to not do it.

2.4.1. Metadata Libraries

A selection of libraries offering access to multimedia metadata as of end of 2017, mostly audio metadata - One source for this e.g. is http://id3.org/Implementations and Google:

Library	URL	Supported Formats	Lines of Code	Comments
jaudiotagger (Java)	http://www.jthink.net/jaudiotagger/	MP3, MP4, Ogg Vorbis, Flac, WMA, partly WAV and Real Audio	> 86000	Obscure class and package structure, more than 500 classes, just a few testcases only (?), still actively developed
jLayer and Java-Zoom (Java)	http://www.javazoom.net/index.shtml	MP3, WAV, ID3v1, ID3v2	> 13600	Project targeting MP3 decoding and playing of MP3s
mp3agic (Java)	https://github.com/mpatric/mp3agic	ID3 Tags (1.0, 1.1, 2.3, 2.4), Read-only ID3 v2.2, MP3 low-level reading (incl. VBR)	> 5500	Still actively developed
BeagleBuddy (Java)	http://www.beaglebuddy.com/	Reads and writes ID3 Tags (1.0, 1.1, 2.3, 2.4), Lyrics3v2, Lyrics3v1, APEv1, APEv2, reads MP3 files CBR and VBR, Xing, LAME, and VBRI Header	> 40700	Focus on being "easy to use"; Last version in beginning of 2015
JID3 (Java)	https://blinkenlights.org/jid3/, https://java.net/projects/jid3lib	ID3v1, ID3v2.2 and ID3v2.3; no ID3v2.4 support	> 30000	Seems to be dead (last version 0.46 in 2005)

Library	URL	Supported Formats	Lines of Code	Comments
Javamusictag (Java)	http://javamusictag. sourceforge.net/	MP3, ID3v1, ID3v1.1, Lyrics3v1, Lyrics3v2, ID3v2.2, ID3v2.3, and ID3v2.4	> 27000	Seems to be the same thing or a fork of JID3
Xuggler (Java)	http://www.xuggle.com/ xuggler	MP3, Ogg (Vorbis, Speex), Flac, AAC, ID3v2 and others	-	Decoder and editing API for various audio and video formats
jFlac (Java)	http://jflac. sourceforge.net/	FLAC, VorbisComment	-	Especially encoding and decoding of FLAC
MPEG-7 Audio Encoder (Java)	http://mpeg7audioenc. sourceforge.net/	MPEG-7	-	Creates MPEG-7 metadata
JAI Image I/O (Java)	https://jai-imageio.dev. java.net/binary-builds. html	EXIF	-	Can read and write EXIF tags from a variety of embedding formats
jmac (Java)	http://sourceforge.net/ projects/jmac/	APE, MonkeyAudio	-	
MyID3 (Java)	https://github.com/ jkauflin/jjkMP3	Audio-Metadaten (ID3)	-	Private engagement, not really to be taken seriously

2.4. RELATED LIBRARIES

Library	URL	Supported Formats	Lines of Code	Comments
id3lib (C/C++)	http://id3lib.sourceforge.net/	Audio-Metadaten (ID3)	-	
Mutagen (Python)	http://pypi.python.org/pypi/mutagen/1.12	Audio-Metadaten und -Container-Daten (ID3)		

Table 2.1.: Competitor libraries compared

The analysis shows that as of now, the biggest competitors would be jAudio-Tagger, mp3agic, BeagleBuddy and JID (which seems dead) from a metadata perspective and Xuggler as well as jLayer from decoding and editing perspective (if `jMeta` should ever try to go into this direction).

Drawbacks of Existing Metadata Libraries

Each of the mentioned libraries specializes itself to just a few formats. Saying this, applications are only likely to be satisfied with them if they just need to support those formats. If they do require more, they need to use multiple libraries or extend the existing ones or wait for new features.

Second, the architecture and extensibility of the existing libraries is not convincing. Most of the ID3 libraries e.g. open-heartedly show their very internals, which does not make it clear what really distinguishes "public API" and the private parts - with the usual consequences. Users might rely on private implementation aspects that are changed later, or if it is known that users do so for specific parts, the library evolution might get constrained by this, forcing duplication and maintenance of actually obsolete code.

Another smell of most of the libraries is their sheer volume: While mp3agic still seems humble in terms of "only" about 6000 lines of code (including comments and blank lines), it also does not offer so much features. The other libraries can really be considered big, topping to about over 86000 lines of code for jaudiotagger. These libraries also do not show an obvious structure or core concepts springing to one's eyes. Maintainability and especially extensibility of such rather "hardcoded" libraries might be not too easy.

Users / software needing to support a broad variety of formats - when using these formats - likely need to implement a kind of plugin mechanism for easier extensibility themselves.

Advantages of `jMeta`

There are alreads so much library - why do we need `jMeta`? If it wants to do things better, a lot of effort is required. Is that worth it?

There are multiple aspects where `jMeta` can do better than existing libraries:

- `jMeta` should target container formats on a very abstract and generic level, yet still providing access to the bare details of each format; this can go as far as providing a generic framework for parsing and writing any multimedia container format, may it be audio, video, image or text content.

- Applications whose core asset is extensibility and rich variety of supported formats do not have to use a dozen or so third party libraries having completely different programming, license and support models as well as performance characteristics - provided `jMeta` actually offers support for all formats, which is of course not necessarily the case

- However, at least such applications do not need to reinvent the wheel by coding their own extensibility mechanism, but they just rely on the extensi-

bility mechanism by using `jMeta`; they can code their own `jMeta` extension to support another format. The goal of `jMeta` is that doing so is easier for such applications than using another 3rd party library to enable support for such a format.

- Still, `jMeta` is not a huge Uber JAR containing all supported formats, but it is modular, where applications just need the core of the library plus an extension module per format they want to support.

- `jMeta` also targets to offer an easy to learn and use API for such applications.

All that said, the benchmark for how good `jMeta` really is, is as follows:

- It should be easier to use as BeaglyBuddy which claims to be easy to use

- It should be much less complex (means to say: much less classes and lines of code) than jaudiotagger or BeagleBuddy

- Supporting a new, averagely complex, previously unsupported data format does not take an experienced Java programmer (who never did write a `jMeta` extension) more than one man day!

- Likewise, we also want to compete with other libraries in terms of performance: `jMeta` must at least be comparatively fast as the most important competitors for Java, ideally of course it should be faster

2.4.2. Multimedia Libraries

Can `jMeta` cooperate, i.e. reuse or integrate with existing Java multimedia libraries? This question is not really answered in the following sections. The general answer is: No, `jMeta` will neither be some kind of plugin for the existing libraries, nor will it depend on them, nor will it consider the requirement of easy cooperation or integration with this libraries in any way.

For now, we just want to see what is existing in the wild in terms of Java multimedia libraries, mostly audio and video. This evaluation might point future directions for `jMeta` if it goes to probably superseding or extending the existing options.

All or most of the multimedia libraries listed here seem to offer some way of reading or writing multimedia metadata. But mostly, these libraries focus on streaming, playing, encoding and decoding on high performance. The metadata is just a side-product that seems to be offered most of the time via a rather inconvenient API.

Xuggler and Humble Video

Cite from the ebsite: "Xuggler is the easy way to uncompress, modify, and recompress any media file (or stream) from Java. ... Xuggler allows Java programs to decode, encode, and experience (almost) any video format."

It does not seem to be based on GStreamer or FFMPEG or JMF. It does not become clear which formats are supported by the library.

The official Github page of Xuggler states it is outdated and humble video should be used. The name suggests Humble Video is mainly focused on video, not audio such as MP3.

JLayer

Cite for JLayer: "JLayer is a JAVA library that decodes, converts and plays MP3 files in real-time. JLayer supports MPEG 1/2/2.5 Layer 1/2/3 audio format. JLayer doesn't need JMF."

It does also not seem to rely on GStreamer or FFMPEG but seems to be a "native" Java only implementation for encoding and decoding MP3 audio data.

Java FX and GStreamer

JavaFX is an Oracle library to support with platform-independent handling of user interfaces as well as multimedia content. So, it is not only "GUI" that actually replaces Swing and AWT, but also handling of images, video and audio content as well as even 3D graphics, thus somewhat replacing the obsolete Java 3D.

So it has a quite broad usage space. However, there is also some muttering that it might be dead or at least does not have a bright future.

For local GUIs it might still be a good option. What about multimedia playback, editing etc.? The media engine part of JavaFX is based on GStreamer. GStreamer is an extensive audio and video library written in C and nevertheless platform-independent by being ported to a lot of platforms and architectures. It also supports reading and writing tags, but in a very specific generic API which does not offer too much comfort. But how does this go together with JavaFX? First of all, GStreamer also offers a Java binding, i.e. can be called from Java applications where any installed GStreamer plugins for formats can also be used. This interface is most probably also used by JavaFX. JavaFX then offers a class named MediaPlayer with a method chain `getMedia().getMetadata()`, just returning a map (String to Object). There seems to be no documentation which objects might get returned. Furthermore it just seems to be read-only, there does not seem to be any way of writing tags with JavaFX.

FFMPEG

FFMPEG can be seen as direct competition to GStreamer, being a platform-independent framework and toolkit to record, convert and stream audio and video content. It is also written in C/C++ and supports a variety of formats.

JMF and FMJ

The Java Media Framework is an official Java library that is delivered with J2SE *desktop* technology. The most recent version is 2.1.1e and dating back to 2001. Which actually means: It is dead. However, we still consider it a bit here. JMF

can be used by Client as well as server applications. JMF was packaged with an MP3 decoder and encoder until 2002, but removed due to licensing issues. Since 2004 there is an MP3 playback only plug-in.[1]

FMJ is an Open Source Alternative, that is API compatible: `http://www.fmj-sf.net/`. But FMJ also seems to be dead.

JMF comes in four JAR files:[2]

- JMStudio: Simple multimedia player application

- JMFRegistry: An application to manage different JMF settings and plug-ins

- JMFCustomizer: Allows creation of a simple JMF JAR file containing only those JMF classes needed by the client application

- JMFInit: Inititializes a JMF application

JMF contains platform-specific *performance packs*, i.e. optimized packtes for Linux, Solaris or Windows.

Features: JMF deals with time-based media. The JMF features can be summed up as follows:[3]

- Capture: Read multimedia frame data of a given audio or video signal and encode it into a specific codec in realtime.

- Playback: Play multimedia data, i.e. display videos on screen or play music on audio output devices.

- Stream: Access multimedia streams

- Transcode: Convert media data of a given codec into another codec without first needing to decode

Criticism: [WikJMF] summarizes some negative feedback for JMF:

- A lot of codecs such as MPEG-4, MPEG-2, RealAudio and WindowsMedia are not supported, MP3 only as plug-in

- No maintenance or extension by Oracle, it is dead

- No editing functionality, i.e. modification of multimedia content

- Performance packs only for just a few platforms

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[1]see [WikJMF].
[2]Siehe [WikJMF].
[3]Siehe [JMFWeb].

Basic concepts of the API Reading of multimedia data is abstracted using
`DataSources`, while output goes to `DataSinks`. No specifics of supported for-
mats are provided for direct API access, they can just be played, processed and
transcoded, while the latter is not supported for all formats. A `Manager` class is
the primary API for JMF users.[4]

The API documentation shows that JMF is quite complex and essentially time-
and event-based.[5] It offers possibilities to read raw binary data via a method `read`
of `PullInputStream`. However, JMF controls processing starting at the source,
i.e. from a file or stream.

JavaSound

JavaSound is Oracle's sound processing library. It has some things in common
with JMF, but can be considered quite low-level, as it also offers modification
functionality for audio data. It also supports MIDI devices.[6] It can also be
considered dead, unfortunately.

Basic concepts: JavaSound essentiall offers the classes `Line` (representing an
element in the audio processing pipeline), the derived classes `Clip` (for playing
audio data) and `Mixer` (for editing audio data). The library can read from streams,
files as well as in-memory bytes. It also offers "transcoding" functionality to
convert between different formats.

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[4]see [WikJMF].
[5]See [JMFDoc].
[6]See [WikJavaSound].

3. Basic Terms

Here we define basic terms used throughout the whole design concept.

3.1. Metadata

Metadata in this document is short for digital metadata that are not necessary to parse the actual described (audio, video or image) data. Metadata semantically and structurally describes other data. The goal of jMeta is especially reading of metadata for audio and video data sets, e.g. title, artist etc. The structure of metadata is defined by a METADATA-FORMAT.

If it is specifically about technical metadata needed to parse a data structure, e.g. in the container header, we call it *Parsing Metadata*.

3.2. Data-Formats, Metadata-Formats and Container-Formats

A DATA-FORMAT defines the structure and interpretation of data: Which bytes or characters of which value and in which order have what kind of meaning? Usually, a data format describes how a consecutive block of bytes (i.e. a DATABLOCK) is built up by a number of so-called FIELDS or child DATABLOCKS.

METADATA-FORMATS are data formats that define the structure of digital metadata. Examples include: ID3v1, ID3v2.3, APEv1, MPEG-7, RDF/XML, Vorbis-Comment and others.

CONTAINER-FORMATS are a more general form of DATA-FORMAT optimized for storing, transporting, editing and seeking multimedia PAYLOAD data. Examples are: MP3, Ogg, TIFF, QuickTime, JPEG 2000, PDF and others. Metadata formats can also be considered as container formats.

An example for other DATA-FORMATS is HTML. You can argue that it is neither a METADATA-FORMAT nor a CONTAINER-FORMAT. XML is a DATA-FORMAT that itself can be used to define further XML DATA-FORMATS. Some XML DATA-FORMATS are METADATA-FORMATS, e.g. MPEG-7, MPEG-21 or P_Meta.

3.3. Binary vs. Textual Data Formats?

The terms *binary format* and *textual format* are sometimes rather misleading and not very clear to distinguish. A textual format is clearly a format where all information, might it be parsing metadata or content, must be interpreted as text of a specified encoding. So you basically need text processing for this. In contrast, binary formats might use chunks of bytes that need to be interpreted

as integers or other numbers according to a specific byte order. However, there are also formats such as Lyrics3v2 which fully consists of textual characters, no integers in the way. Nevertheless, it has a lot of similarities with e.g. ID3v2.

So a better distinction is:

- CONTAINER-FORMATs in `jMeta` are data formats that define payload lenghts in separate parsing metadata fields; their most common representation is as binary format, but some formats such as Lyrics3v2 use text characters also for parsing metadata. Saying this, all common METADATA-FORMATs are seen as specific CONTAINER-FORMATs.

- In contrast to this, a *textual delimited data format* is a format where all bytes need to be interpreted as characters, and thus also parsing metadata is represented as strings. In addition, these formats do not have fields that specify lengths, but they use metadata delimiters to mark start end (optionally) end of a field. Examples are XML, HTML, JSON, LaTex or YAML.

3.4. Transformationen

A DATA-FORMAT may define TRANSFORMATIONs. A TRANSFORMATION describes a way how read or to be written data needs to be transformed to fulfill specific needs. You can envision this as kind of encoding of the data. In contrast to the fixed data format specification which describes in detail how binary data is coded and needs to be interpreted, TRANSFORMATIONs are optional features that are dynamically applied to certain areas of the data. Partly, TRANSFORMATIONs can also be defined by users of the data. Examples are the TRANSFORMATIONs defined by ID3v2: Unsynchronization, Encryption and Compression.

3.5. Datablocks

A DATABLOCK is a sequence of bytes that together form a logical unit (i.e. an object or entity with a specific meaning) in terms of the underlying DATA-FORMAT. Each DATABLOCK belongs to exactly one DATA-FORMAT. It can be assigned a current length in bytes. There are several concrete types of DATABLOCKs that are described in the following sections.

The actual detailed meta model of DATABLOCKs is defined later in the detailed `jMeta` design sections of this document for `DataFormats`.

3.5.1. Container: Payload, Header, Footer

An important type of DATABLOCK is a CONTAINER: It consists of zero, one or several HEADERs, exactly one PAYLOAD and zero, one or several FOOTERs. All of these are *child* DATABLOCKs. CONTAINERs are a common concept for container formats: The HEADERs and FOOTERs describe the CONTAINER in terms of its length, size and other properties. The PAYLOAD contains the interesting data, e.g. the multimedia data to be extracted, played or viewed. FOOTER essentially

allow for backward or reverse reading. Most of the DATA-FORMATs specify a
generic structure of a CONTAINER, with specific containers with specific purpose,
but allowing user-defined new CONTAINERs at the same time, i.e. the format is
extensible.

3.5.2. Tag

A TAG is a special CONTAINER whose purpose is to store metadata. It can either
belong to a standalone METADATA-FORMAT ore to a more general CONTAINER-
FORMAT. Especially audio, video and image metadata formats use this term
when talking about such a DATABLOCK in a file or MEDIA STREAM, e.g. the
ID3 or APE TAGs. It term originates from "tagging" something with additional
meta-information, as you'd attach a label to describe the song, video or image.

The following figure shows the basic structure of a TAG, showing other basic
terms:
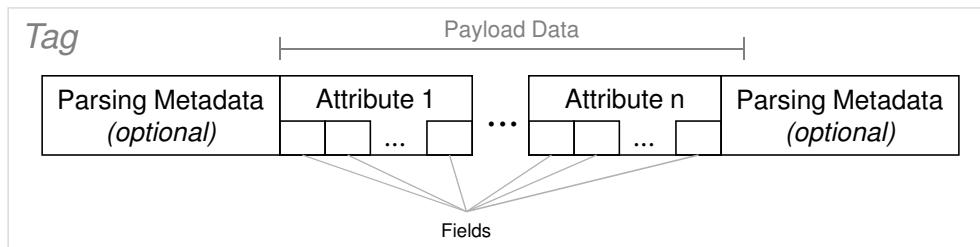
Figure 3.1.: Structure of a TAG

The most important parts of a TAG are the ATTRIBUTs.

3.5.3. Attribut

An ATTRIBUT is a part of a TAG that contains the valuable metadata information
in a key-value manner. Common examples are artist, title, album, composer etc.
of a piece of audio. Often, an ATTRIBUT is also a CONTAINER in a sense that it
has a HEADER and PAYLOAD. The HEADER may help to define the type (artist,
title, album) of the ATTRIBUT as well as the size of the PAYLOAD. The PAYLOAD
contains the actual information in an encoded way, e.g. the name of the artist or
title of the piece of audio.

Most of the ATTRIBUTs have a simple main value that can be given. However,
there are also more complex ATTRIBUTs that consist of many values in form of
child CONTAINERs or FIELDs.

In each metadata format, an ATTRIBUT has a format-specific name, e.g.:

- ID3v1, Lyrics3: Field

- ID3v2: Frame

- APE: Item

- Matroska: SimpleTag

- VorbisComment: User Comment

3.5.4. Fields

A FIELD is a sequence of bits that together have a specific meaning in a given DATA-FORMAT. They form the leafs of the data block hierarchy by ultimately containg the raw data. A DATA-FORMAT describes how a specific DATABLOCK is built up by a specific sequence of FIELDs. A FIELD has a range of possible values and interpretations of these values. Often, one part of the value range is defined as "reserved" to ensure a bit of flexibility in extending the data format. Fields can be fixed-size or of variable length. If they have a variable length, there is often either another field specifying its length, or it is terminated by a specific sequence of bytes or characters.

3.6. Medium

A MEDIUM incorporates both the physical location of the data containing DATA-BLOCKs to read and write as well as the way of accessing this data. It may be a file, a stream or even plain memory.

4. Requirements and Exclusions

Here, all explicit high-level requirements for `jMeta` in version `0.5` are listed, including some explicit exclusions. Exclusions have the meaning that a given feature is explicitly not supported in the current version, and it might be like that also in future versions. No design is made for supporting them. However, it might well be that for future versions of the library, these decisions are changed and previously excluded features are then supported. The question is: Why listing exclusions at all? How far do they go, so will there be an exclusing stating that `jMeta` is not an operating system, e.g.? Not that far. Exclusions are only meant to demonstrate lack of features that popped up during the design phase and that could be desirable for `jMeta` users.

In contrast to exclusions, there are potential features such as new metadata or container formats to support. These are neither explicitly excluded nor already planned for future releases.

4.1. REQ 001: Reading and writing of human-readable meta data

`jMeta` can read and write meta data in a *human-readable format*. That means librar users do not have to read (and interpret) or write raw binary data.

Rationale: This is the general core functionality of the library and must be supported.

A list of supported data formats in the current version is given in "2.4.2 Features:".

4.2. REQ 002: Read container formats

`jMeta` must be at least able to read popular and wide-spread container formats. Writing support is optional.

Rationale: Multimedia meta data is often embedded in container formats or an integral part of their specification. `jMeta` must be able to identify and parse container segments in order to skip them to find the actual start of a meta data tag, or to read their meta data content. Writing is optional because `jMeta` cannot offer encoding functionality, so just writing header information and raw binary data that has been encoded by another library could be offered.

4.3. REQ 003: Fulfill specification of supported data formats

As far as there is an official specification for a supported data format, this specification must be fully supported by jMeta, that means all encoding types, optional headers, data transformations (e.g. encryption), padding and other features that are included in the specification, as well as any generic attributes or containers must be readable and writable. It is not necessary that jMeta explicitly supports unspecified attribute types that might be popular but not defined by the specification. Such attributes should however be accessible using the generic attribute mechanism offered by most data formats.

Rationale: This ensures that all meta data or container format blocks that adhere to their specification can be read by jMeta, and furthermore, that jMeta itself generates data that is compliant to the specification. Second, the user can use jMeta to use specific data format features in a convenient way without needing to implement this himself.

4.4. REQ 004: Access to raw data via jMeta

In addtion to the access to human-readable meta data ("4.1 REQ 001: Reading and writing of human-readable meta data"), it must be possible to explicitly read and write raw data on byte level. jMeta must offer fine-grained access to fields of binary data.

Rationale: Thus, user could implement parsing themselves without needing to use high-level functions. In some rare cases this might be necessary to circumvent some issues with the data written by some other tool. This channel of access is offered to users such that they are not forced to completely skip jMeta and implement raw access to supported media themselves, leading to also sync and consistency issues when doing this in parallel to the access by jMeta.

4.5. REQ 005: Performance as good as other Java meta data libraries

The performance of jMeta on all supported platforms must be as least as good as the performance of competitor Java meta data libraries such as jaudiotagger, mp3agic or BeagleBuddy. A corresponding reasonable benchmark needs to be set up with published code to demonstrate this. It is out of scope to make jMeta as fast as high-performance encoding or decoding libraries on C++ basis such as gstreamer of ffmpeg.

Rationale: jMeta targets to be a good replacement for any existing Java multimedia tagging library, and thus it is clear it should at least perform at the same level or even better.

4.6. REQ 006: Fehlererkennung, Fehlertoleranz, Fehlerkorrektur

Ergänzend zur "4.3 REQ 003: Fulfill specification of supported data formats" muss die Library aber auch *fehlertolerant* sein, so weit möglich. D.h. u.a., das Spezifikationsverstöße und fehlerhafte Parsing-Metadaten erkannt werden, und dies - soweit nicht unumgänglich - nicht zum Abbruch des Parsens mit einem Fehler endet. Verstöße werden protokolliert und wenn möglich automatisch korrigiert (optional, wenn es der Library-Anwender wünscht).

Rationale: Altanwendungen oder andere Libraries schreiben Datenformate manchmal nicht 100% spezifikationskonform. Zudem sind nicht alle Spezifikationen eindeutig oder genau genug, sodass Varianten entstehen könnten. Trotz Vorliegen fehlerhafter Daten soll der Anwender der Library in die Lage versetzt werden, Daten dennoch auslesen und ggf. sogar korrigieren zu können.

4.7. REQ 007: Extensibility for new Metadata and Container Formats

jMeta must be comfortably extensible with new container or metadata formats. As the minimum level, easy extensibility by the library developers must be possible. As the maximum level of extensibility, also end users with programming experience must be able to easily write extensions without too much configuration or boilerplate code.

Rationale: A wealth of already existing meta data and container formats is yet out there. Just the formats with major importance are supported as of now by jMeta. Furthermore, we might expect new meta data or container formats in future. The extensibility mechanism first of all guarantees an easy extensibility by a 3rd party, e.g. lib name users or also other vendors. The extensibility also ensures a longer life time of the library. In the maximum level "Extensibility by end users", this is a clear differntiation criterion to other libraries that do not offer this level of extensibility. Last but not least, this allows easier maintenance (i.e. extension) by the library developers itself if they decide to bundle additional format support extensions with the core library in a new release.

4.8. REQ 008: Read and write large data blocks

jMeta must be able to read and write large amounts of data efficiently. With "large" we mean that jMeta must support data blocks with maximum size of $2^{63} - 1$ bytes. The length of payloads must be interpreted correctly. Because of "4.4 REQ 004: Access to raw data via jMeta", also reading and writing of raw data must be supported without necessarily causing scarcity of available memory, e.g. by chunk-wise reading possibilities. In general, jMeta must use mechanisms to avoid OutOfMemoryErrors, unless the user forces this by reading the whole binary data of a block into memory.

Rationale: Especially in the domain of video container formats, payloads or at least files with multiple gigabytes are very common. Yet, still $2^{63} - 1$ bytes as upper limit should suffice for some years or decades to come. Supporting this is for sure also a plus compared to other competitor libraries that might not explicitly support large files.

4.9. REQ 009: Selective Format Choice

An application using `jMeta` must be able to selectively choose those formats that it wants to support. This is not only necessary for runtime, but also for the library extension packages it wants to use.

Rationale: Audio applications do not need extensions for video or image formats. Applications can minimize the runtime and memory (both HDD and RAM) overhead by choosing as few extensions as really needed.

4.10. EXCL 001: Reading media streams

`jMeta` in its current version `0.5` does not explicitly support reading meta data or containers from media streams consumed e.g. from the internet. It might offer optional starting points for this by e.g. in principle supporting access to `InputStream`s. But it does not offer an explicit API or examples, nor do we create specific test cases for media streams. Furthermore, media stream specific tag formats such as `IcyTag` are not in scope of the current library version.

Rationale: Combined applications such as recorders or players whose main task is playing make more sense for this, as they are not only interested in meta data. Supporting streaming media in addition might overly complicate the design and API of the current library version, so this might be left for future versions to come.

4.11. EXCL 002: Support for XML meta data

There are also XML meta data formats out in the wild. They are not used very often for multimedia meta data, but cases exist. `jMeta` does not support reading and writing of XML meta data format in the current version, but only specializes to binary formats. **Rationale:** Binary meta data formats still seem to rule the scene due to their compactness. It would be absurd to design a generic library that can parse both XML and binary formats with the same code, as XML is usually efficiently read and written using streaming parsers and validated using schemas, where excellent APIs already exist. It is left for the future to offer built-in support for XML metadata in `jMeta` via an easy API.

4.12. EXCL 003: No user extensions for `jMeta` media

Extending `jMeta` with new media to support - on top of the out-of-the box supported media - is not supported.

Rationale: The mechanisms available should cover 80 to 90 percent of the use cases. Extensibility by new media might increase the complexity of `jMeta` itself and the extension mechanism in specific, without adding real-world use cases really needing it. It is currently not clear which media beyond streams, byte arrays and files might be candidates for extending `jMeta`. Should new media make sense in future, a new core release can be created to also support media extensions.

4.13. EXCL 004: `jMeta` is not a (high-performance) encoder or decoder

Even though it would be tempting, `jMeta` currently is not a encoder or decoder for multimedia content, especially not a high-performance one. It is not the target to extend this library to be that, but you never know. However, it can be the basis for a Java-based encoder or decoder pack, as it offers bit-wise parsing and other raw data access functionality for container formats. But there is no specific design into that direction, especially no means for specific multi-threading built-in support, means users are left to leverage multiple cores themselves as necessary.

Rationale: Audio, video and image formats as well as corresponding encoders are extensively complex. A huge variety of great libraries and tools is already existing. For high-performance needs, especially GStreamer and FFMPEG seem to rule the scene. `jMeta` can never compete with that and it would mean to *just stop* the project when trying to do just that. Instead, we can offer the primitives for Java developers who might want to develop their own (probably not very high-performance) codecs. Maybe in the very far future, `jMeta` could offer integration functionality to plug-in existing codec implementations somehow conveniently, such that it can be used on its own as a basis for Java transcoding and player/viewer applications.

5. Reference Examples

To proof conformance with the `jMeta` requirements, a set of (mostly) real-life examples for all supported formats is used. The examples are used to illustrate design decisions and also to verify them. In this chapter, these examples are presented for short. The concrete detailed structures of each data format is described in [?].

Note that the sizes of the data blocks in the following illustrating example figures do not have any specific meaning.

5.1. Example 1: MP3 File with ID3v2.3, ID3v1.1 and Lyrics3

The following figure shows the first example, an MP3 file with three TAGs, ID3v2.3, Lyrics3v2 and ID3v1.1. All are located at the end of the file:
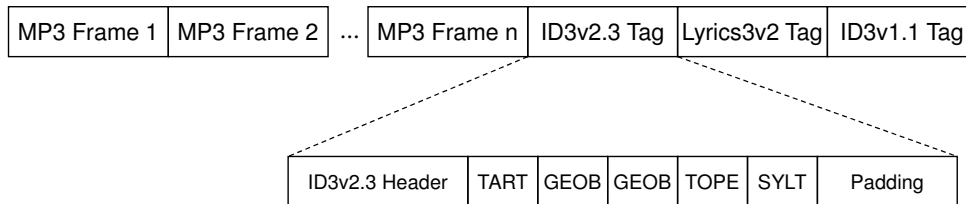
Figure 5.1.: Example 1: MP3 file with two tags

The ID3v2.3 tag has several frames, including two `GEOB` frames. Furthermore, it has some padding within. Each of the MP3 frames corresponds to the MPEG-1 elementary stream audio format.

5.2. Example 2: MP3 File with two ID3v2.4 Tags

The following figure shows the second example, an MP3 file with two ID3v2.4 TAGs, one at the beginning, the other one at the end of the file:
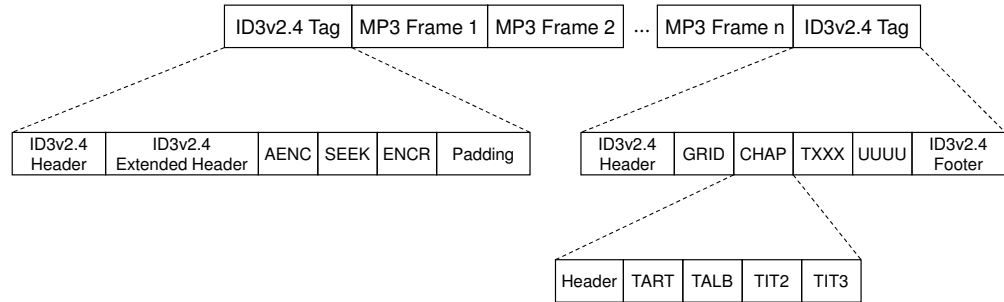
Figure 5.2.: Example 2: MP3 file with two ID3v2.4 tags

The two ID3v2.4 tags are virtually connected by a `SEEK` frame. Both have several specialties described in [?].

5.3. Example 3: Ogg Bitstream with Theora and VorbisComment

The following figure shows the fourth example, an Ogg bitstream that contains Theora payload data with a corresponding vorbis comment:
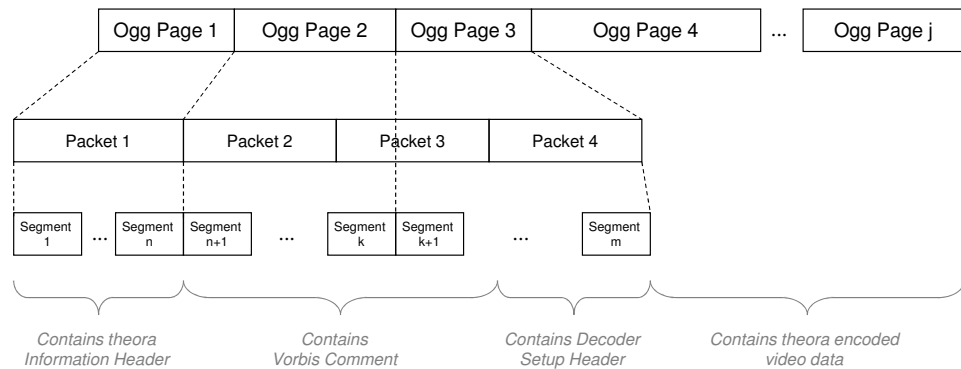
Figure 5.3.: Example 4: Ogg Bitstream with Theora and VorbisComment

The example is complex on first sight. In an Ogg bitstream, physical and logical structure are not necessarily the same. The physical structure is built by pages, packets and segments, while the logical structure is the structure of the wrapped data. We took theora video data as an example, but its basically arbitrary, as the codec does not really matter. What matters is where the Vorbis Comment, one of the supported data formats, is stored. This unfortunately depends on the embedded codec. In this example, the vorbis comment starts in the second page and spans over two packets. The second of these packets spans over two Ogg pages.

Part II.

Architecture

In this part, the high-level structure of `jMeta` is defined. This is done in two refinement levels:

- The technical architecture shows the technical environment and parts of `jMeta`

- The functional architecture shows and describes the functional components of `jMeta`

6. General Design Decisions

This chapter presents all general design decisions that have a big impact on the overall architecture. It is usually very hard to revert any of those design decisions. As they generally affect the whole library, they have no direct relation to specific requirements, but build the framework to be able to fullfill those requirements.

6.1. Using Java SE 9

> **DES 001:** jMeta **is based on Java SE 9**
> jMeta is developed based on the "latest update" of Java SE 9. Migrating jMeta towards newer Java versions is considered on a regular basis.
>
> **Begründung:** Java as programming language is well established and in wide use by a big number of world-wide developers. Furthermore, Java is platform-independent. In principle, porting jMeta to other platforms, to Java ME or to Java for e.g. smart phones (e.g. Android) should be less effort than porting an equivalent C/C++ library. The author has long experience with Java programming, so this should facilitate productivity. The competitor libraries in the Java environment are good, but jMeta can be even better. The current (state 28th of November 2017) version Java SE 9 is used, because we want to create a modern library using the newest language features, libraries and programming models in the Java world. Furthermore, it is guaranteed that we get longer support for this Java version than for the previous ones.
>
> **Nachteile:** Applications being based on Java 7, Java 8 or older are not supported by jMeta. This would especially effect Java EE applications where it seems not yet possible to use Java SE 9 for some application servers.

6.2. Use of 3rd Party Libraries

> ***DES 002:*** `jMeta` **uses as few 3rd party libraries as possible**
> `jMeta` uses mostly only the libraries offered by Java SE. In the productive code
> of the library, no dependencies to other 3rd party libraries are used except for
> logging.
>
> **Begründung:** Additional dependencies could create overhead or question
> marks when it comes to building, shipping, testing or licensing. Furthermore,
> you might at one point in time reuse a well-tested and documented 3rd party
> library, and in the next year, it might get abandoned or bugs show up that do
> not get fixed. We ensure that bugs are just bugs that we can fix ourselves and
> we do not depend on other library developers.
>
> **Nachteile:** Sometimes this might mean "do it yourself" instead of reuse.

6.3. Component-based Library

> ***DES 003:*** `jMeta` **is component-based**
> `jMeta` is consisting of so-called components as defined in the follow-up
> sub-section. Each component has a well defined responsibility, a public API that
> can be used by all other components as well as a private implementation part
> that must not be used by other components.
>
> **Begründung:** Structuring a big library into modular parts helps to manage the
> complexity of the library during planning, design, implementation and
> maintenance. By using a reasonable component structure, clear responsibilities,
> dependencies and decoupling of unrelated parts is achievable. Changes in
> implementation parts of a component do have less probability to affect other
> components, as they do only depend on the API of the component.
>
> **Nachteile:** Probably a little bit more overhead due to sometimes following
> "conventions" where an easier structure would be possible

6.3.1. Definition of the component term

A *component* in `jMeta` is *a self-contained software module with clearly defined
task*. It offers *services* the can be used via a *well-defined interface (API)*. These
services are used both by the users of `jMeta` as well as by other components of
the library.

The following figure shows a component in `jMeta` schematically:
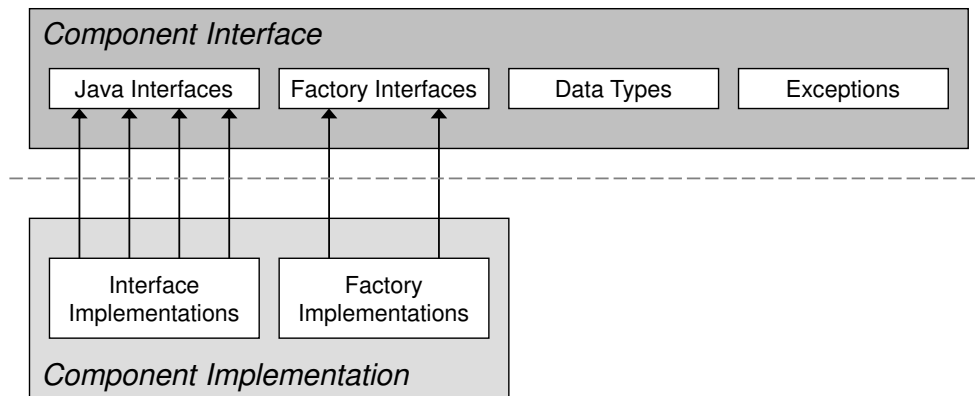
Figure 6.1.: Structure of a component

A component interface consists of one or more Java interfaces, the so-called service interfaces, exceptions as well as data types.

- *Service interfaces* offer the functional API of the component, each method corresponds to a service of the component. A single Java interface is use for a clear defined subtask of the component. Some service interface have factory methods that provide access to further service interfaces of the component.

- *Data types* are (mostly) constant Java classes that are usually used to hold data for service input and output parameters. Usually they are value types, but sometimes they are also representing a specific entity such as a medium.

- *Exceptions* are functional errors. These are mostly unchecked exceptions signaling a specific error condition, in rare cases we use unchecked exceptions if the caller can handle the situation.

In addition, a component might have data ownership for a specific kind of relevant data. This means that this data can only be read or manipulated via using the public API of this component, and by no other means.

6.3.2. Design Decision for using components

***DES 004:* Components decoupled by a light-weight service locator pattern**

To ensure low coupling between components, they must know each other only via their interfaces. A component can obtain a reference to a service implementation without directly depending on the implementation class itself by using a service locator pattern, specifically the Java SE `ServiceLoader`.

Begründung: We want to decouple components. To achieve this, it must not be allowed for components to instantiate service implentations of other components directly, because service implementations are not part of the public interface of a component. A service locator exactly offers to obtain a service implementation reference without depending on it. For a library such as `jMeta`, neither JavaEE nor Spring or CDI dependency injection are valid options. Google Guice is not chosen because of DES 004. Java SE `ServiceLoader` is a very easy to use and fully sufficient facility.

Nachteile: No disadvantages known

***DES 005:* Singleton Components**

Each component offers a single *main API service interface* that itself offers access to any other service interface the component provides.
From a runtime perspective, each main API service interface thus has a single (ideally stateless) implementation, which you could refer to as "singleton".

Begründung: A main API service interfaces is purely procedural. There is just one implementation of component allowed at runtime. We just need one instance for each component at runtime, as it is stateless. This safes memory and initialization overhead.

Nachteile: No disadvantages known

DES 006: **API and Implementation Layers**
Each component offers its services, exceptions and data types on an *API layer*.
This layer is a horizontal layer cutting through the whole library and
representing the public API of the library. Also per component, it is the public
API of a component. Compile-time dependencies from user code to `jMeta` as
well as between components are only allowed via this API layer. The
implementation layer depends on the API layer and contains any private classes.
An outside component and user code is not allowed to have a compile-time
dependency to implementation layer classes

Begründung: Clear separation of concerns and information hiding. What
implementation layer classes do is their private business, nobody from the
outside world is allowed to directly work with and depend on them.

Nachteile: No disadvantages known

DES 007: **No further subdivision of implementation layer**
It is not necessary to further subdivide the implementation layer into sublayers.
Instead, each component can have an arbitrary package structure in its
implementation layer code.

Begründung: We do not see any reasonable sublayers for `jMeta` that could be
relevant for all components of the library.

Nachteile: No disadvantages known

6.4. Development Environment

DES 008: **Development Environment**
As development environment, we use Maven, Eclipse and SubVersion for `jMeta`.

Begründung: Amazing toolset that leaves not much else to wish for.

Nachteile: No disadvantages known

6.5. Multithreading

> ***DES 009:*** **`jMeta` is not thread-safe**
> `jMeta` is not a thread-safe library and (usually) does not use any Java APIs that are thread-safe.
>
> **Begründung:** In some cases, thread-safety means performance degradation due to synchronisation points. In addition, it almost always means higher complexity. In a non-functional programming language such as Java with a lot of mutable state, it is hard to get thread-safety right. If users need to work with `jMeta` in multiple threads, they have to ensure thread-safety themselves.
>
> **Nachteile:** No disadvantages known

6.6. Architecture

> ***DES 010:*** **Architecture of `jMeta`**
> `jMeta`'s architecture adheres to the technical and functional architecture as descrived in chapters "7 Technical Architecture" and "8 Functional Architecture".
>
> **Begründung:** See architecture discussion in detail in the next chapters
>
> **Nachteile:** See architecture discussion in detail in the next chapters

7. Technical Architecture

The technical architecture allows functional components (i.e. components offering the actual functionality of `jMeta`) to operate in their technical infrastructure. In addition, the technical architecture consists of the layers of each component. We have a component-based layered architecture as defined in "6.3 Component-based Library". The layering has already been defined in the design decisions DES 010 and DES 010. Thus, we just concentrate on a brief overview of the technical infrastructure and the technical base components here.

7.1. Technical Infrastructure

The technical infrastructure describes the environment required to work with `jMeta` as shown in the following figure:
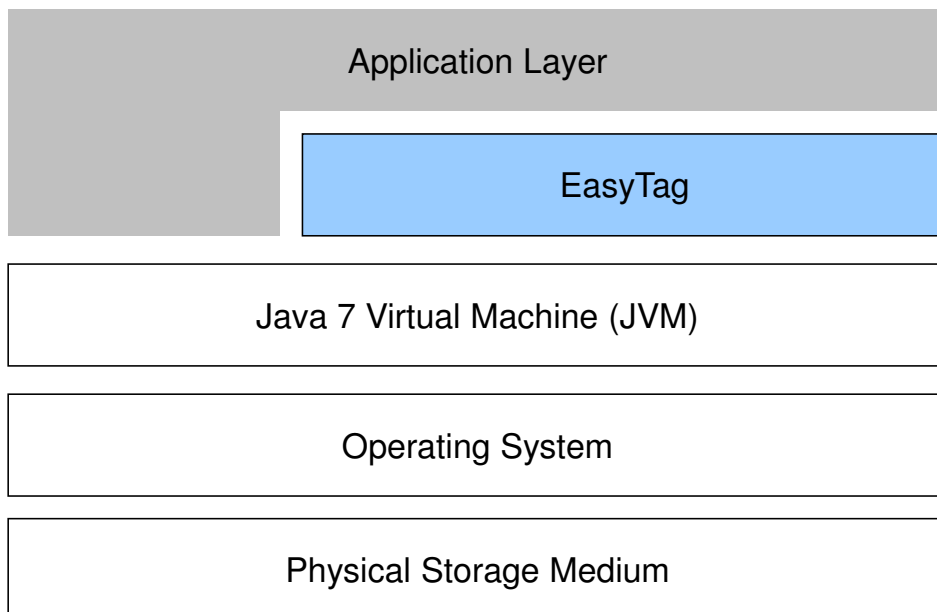
Figure 7.1.: Technical infrastructure of `jMeta`

The technical layers can be interpreted as dependency and communication structure. The application layer is based on `jMeta`, while `jMeta` as well as the

application layer uses Java SE 9. Thanks to this, the library and its using applications are platform-independent and can be used on any platform currently supported by Java. Java SE 9 accesses the operating system, which offers services to access the physical medium.

However, `jMeta` is only developed for Java SE 9 and cannot be used by applications requiring earlier versions.

Each layer only accesses the neighouring layer.

7.2. Technical Base Components

Technical base components are just helpers providing a framework and basis for the functional components of `jMeta`. With "functional" we are referring to the tasks of the library, i.e. reading and writing metadata and reading container data. The necessary base components are:

- Logging

- Service-Locator to achieve a component oriented architecture

- Utility

- Maintaining extensions

Details of these components are given in "III jMeta Design".

8. Functional Architecture

The functional Architecture defines the structuring of the library into functional units, so called functional components according to "6.3 Component-based Library". For completeness, also the dependencies of the functional components with the technical base components is shown in functional architecture diagrams. In addition, the functional architecture also contains basic functional design decisions influencing the direction of the whole library.

8.1. Fundamental design decisions of `jMeta` functionality

The following design decisions are fundamental for the whole library and mostly have a cross-cutting effect. They form the basis for the functional design of all functional library components.

> **DES 011:** **Generic reading and writing according to a format specification**
>
> Reading and writing different CONTAINER-FORMATs is done generically by a central component. A format specification describes which features a CONTAINER-FORMAT has, especially how its DATABLOCKs are structured and how they need to be interpreted. Thus it can be seen as a kind of generic parsing (and writing and validating) instruction of the data format.
>
> **Begründung:** According to the document [MetaComp], CONTAINER-FORMATs and their more specific children METADATA-FORMATs have a lot of things in common, in specific the way how they are structured and parsed. These common properties can be descrubed using a generic format specification. Instead of rewriting specific parsing, writing and validation code for each new supported CONTAINER-FORMAT, all of them can be implemented by the same generic parsing, writing and validation code that is based on the generic format specification.
> This way, in the end, there should be less code, less duplication, and also a higher quality of code as it can be tested easier.
> This design decision also essentially enables to meet the requirement "**?? ??**", as this way it is much easier to extend the library with new CONTAINER-FORMATs.
>
> **Nachteile:** The generic code can probably not be written to support any and every possible future or existing CONTAINER-FORMAT out of the box. Thus there might still be changes required in future. We have to carefully avoid to add format specific code to this generic core code, such that it not again becomes a complex monster, where in the end it would have been better to rewrite code for each extension. The latter risk exists if the formats do not have as much in common as assumed by this design decision. This can make testing or even understanding the generic code extensively hard.
> In addition, there might be some small performance drawbacks, as generic code can of course not as heavily and specifically tuned as format-specific code can.

To mitigate the possible disadvantages of DES 011, we define the following design decision:

DES 012: **It is possible to override generic reading and writing in extensions**
`jMeta` Container-Format extensions are allowed to override specific parts of reading, writing and validation code to adapt them to specifics of their data format.

Begründung: This minimizes the disadvantages of DES 012. In special cases, this can lead to easier or faster implementations. Furthermore, using such hooks, it might not be necessary to blow up the core code by specifics that are actually only relevant for one or just a few concrete formats. Those specifics can then be implemented in the corresponding format's code.

Nachteile: It might not be easy to clearly define and communicate which parts can be overridden and which not.

To also mitigate the risk of too big and complex generic core code, we define:

DES 013: **Format specifics are only defined in extensions**
Any special features of a Container-Format or Metadata-Format that are no common properties/features of a lot of container formats are only defined in the corresponding extensions. That said, the generic core code never directly depends on specifics of data formats, neither syntactically (e.g. compile-time dependencs to format extension; by using if-then-else to do things different depending on the current format) or semantically (e.g. implementing a special feature for just one format, but claim it is "generic"). Only if a special feature of a format can be brought down to a common denominator for all supported formats, it is implemented generically.

Begründung: So wird bereits mit der Kernlibrary selbst das Erweiterungskonzept genutzt und erprobt. Es findet eine strikte Trennung zwischen Kernimplementierung und Format-Spezifika statt, was eine bessere Beherrschung der Gesamt-Komplexität ermöglicht.

Nachteile: No disadvantages known

> ***DES 014:* High-level and low-level API**
> The generic, format-independent core parts of `jMeta` form a kind of *low-level API* for parsing, writing and validating data of a CONTAINER-FORMAT quite generically down to the byte level. The end user of `jMeta` is allowed to use this part of the library directly.
> However, on top of that there is a more convenient and format-specific *high-level API* the user usually uses to access data.
>
> **Begründung:** According to DES 014, `jMeta` has a generic format-independent core part. This could be made private, not to be used by end users of `jMeta`. However, this would not make it possible to fullfill "**?? ??**". At the same time, format-specific extensions need to reuse the core part. We do not want to throw the core part together with these higher-level extensions.
>
> **Nachteile:** No disadvantages known

8.2. Extensions

An *extension* summarizes format-specific content for a given data format, or multiple variations of the data format. Per data format defined by the extension, these are (compare DES 014, DES 014 and DES 014):

- A data format specification which defines DATABLOCKs and their structure and relations.

- An end-user high-level API to comfortably work with the data format, e.g. for creation of DATABLOCKs etc.; this API especially holds the data format identifier which the user can use to work with other components.

- Implementation extensions that might override generic parsing, writing and validation.

As a ground rule, every single extension can but should not define extension code for more than one data format. It might expose more data formats only if these two data formats heavily overlap and are based on each other, e.g. ID3v1 and ID3v1.1. This is to fulfill the requirement "**?? ??**".

Moreover, distinct extensions should never depend on each other, but only on the `jMeta` core to avoid any confusion for the user.

8.3. Functional Architecture Components

The following component diagram shows the functional and technical base components of `jMeta` and their dependencies. An arrow indicates a necessary compile-time dependency. For each format extension, there is exactly one component.
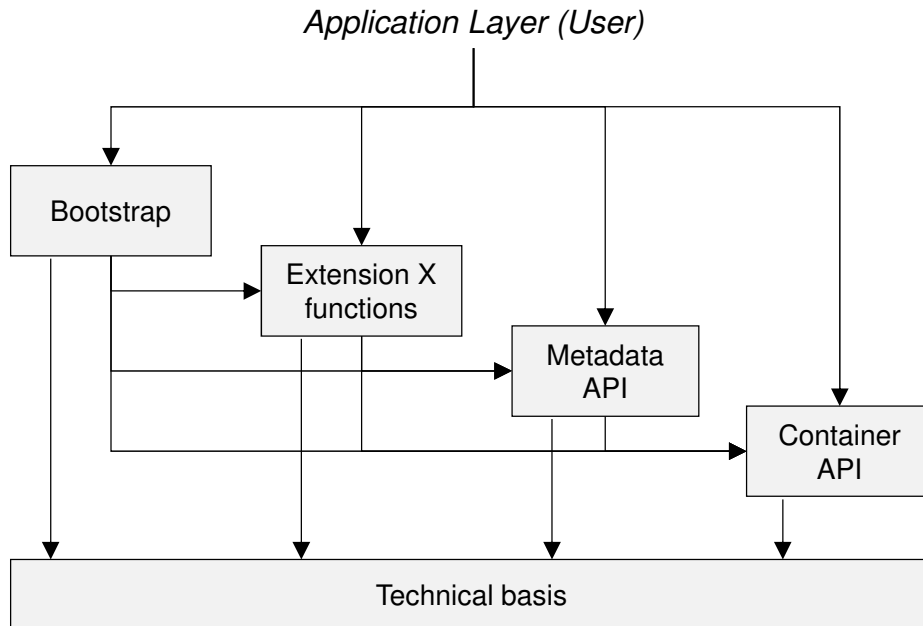
Figure 8.1.: Component diagram of `jMeta`

You can identify a kind of "component layering" (not to be confused with the architecture layering, it is just a grouping of components). At the lowest level we have the technical base components, then followed up by the low-level API components and the high-level API (according to DES 014) on top.

Dependencies to the technical base components are not shown in this diagram, as anybody can (and usually does) depend on them. Note that, due to this, we only list dependencies to technical base components in the component characteristics sections to follow if these dependencies are important and need to be specifically mentioned.

All the components displayed are just briefly described in the next sections.

8.4. Component Characteristics

All components are briefly described by a common structure that looks like this:
   Component Name: The name of the component.
   Task: The main responsibility of the component.
   Controlled Data: Any data the component has ownership for.
   Depends on <Component Name>: Occurring multiple times, once for each component it depends on with a reason why this dependency is necessary.

8.5. Component `EasyTag`

Component Name: `EasyTag`

Task: The entry point for every user to `jMeta`. It loads all extensions and provides access to all other components of the library.

Controlled Data: Keine.

Depends on `ExtensionManagement`: `EasyTag` loads all extensions by using this component.

Depends on `ComponentRegistry`: `EasyTag` uses this component to instantiate all component singletons the user asks for.

8.6. Any extension component

Component Name: Arbitrary, usually the name of the data format the extension implements

Task: Offers the high-level API to work with the data format it implements.

Controlled Data: None.

Depends on `ExtensionManagement`: It needs this dependency to the extension framework because it is an extension.

Depends on `DataFormats`: It implements a specific data format, does needs to depend on data format base classes defined in `DataFormats`.

Depends on `DataBlocks`: Extensions are allowed to override reading, writing and validation of data, thus they can depend on `DataBlocks`.

8.7. Component `DataBlocks`

Component Name: `DataBlocks`

Task: Implements generic reading and writing of CONTAINER-FORMATs and METADATA-FORMATs according to their format specification.

Controlled Data: Accessing raw CONTAINER or TAG data on byte or bit level is only allowed by using this component.

Depends on `Media`: `DataBlocks` must read and write data portions from an external medium, for this it uses `Media`.

Depends on `DataFormats`: Needs access to the data format specification by depending on `DataFormats`. This is necessary to implement the generic reading and writing.

8.8. Component `DataFormats`

Component Name: `DataFormats`

Task: Manages the generic data format definitions for CONTAINER-FORMATs.

Controlled Data: Has control over the data format specifications.

Depends on: No other components except technical base components.

8.9. Component `Media`

Component Name: `Media`

Task: Offers primitive to read and write all supported physical Medium. Hides medium access differences for other components.

Controlled Data: Accessing data of external media is only allowed by using `Media`.

Depends on: No other components except technical base components.

8.10. Component `ExtensionManagement`

Component Name: `ExtensionManagement`

Task: Manages all extensions of `jMeta` generically, i.e. loading and verification.

Controlled Data: Descriptive data for extensions can only be obtained using `ExtensionManagement`.

Depends on: No other components except utility.

8.10.1. Component `ComponentRegistry`

Component Name: `ComponentRegistry`

Task: Implements the service locator functionality to enable components to depend only on the API of another component.

Controlled Data: Only via `ComponentRegistry`, access to metadata about components of `jMeta` is possible.

Depends on: No other components except utility.

8.10.2. Component `Utility`

Component Name: `Utility`.

Task: Offers diverse (technical) cross-functional stuff that needs to be used by most if not all other components, e.g. helper functionality to implement design-by-contract.

Controlled Data: None.

Depends on: No other components.

Part III.

jMeta Design

This part defines the design of the components per subsystem, based on the components and subsystems defined in the previous chapters.

9. Cross-functional Aspects

Als Design wird hier die Fortsetzung der skizzierten Architektur im Detail verstanden.

In diesem Abschnitt werden übergreifende Aspekte des Designs von `jMeta` behandelt, die keinen Bezug zu nur einer Komponente oder nur einem Subsystem haben. Es handelt sich meist um die bekannten *cross-cutting concerns*.

9.1. Generelle Fehlerbehandlung

Hier wird der generelle komponenten-übergreifende Ansatz der Fehlerbehandlung in `jMeta` behandelt. Es werden also keine konkreten Fehler bestimmter Komponenten behandelt.

9.1.1. Abnormale Ereignisse vs. Fehler einer Operation

Gemäß [Sied06] können wir Fehler wie folgt kategorisieren - die Kategorien werden hier zusätzlich untergliederd und benannt:

- *Kategorie 1: Abnormale Ereignisse*: Ereignisse, die nur selten auftreten sollten und spezielle Behandlung erfordern.
  - Verbindung zu einem Server ist abgebrochen
  - Eine Dateioperation schlägt fehl
  - Eine Konfigurations-Datei oder Tabelle, deren Existenz vorausgesetzt wird, ist nicht vorhand
  - Ein externer Speicher- oder der Hauptspeicherplatz ist erschöpft

- *Kategorie 2: Fehler einer Operation*: Eine Operation kann mit einem Fehler oder mit einem Erfolg beendet werden. Fehler einer Operation kann man von abnormalen Ereignissen dadurch unterscheiden, dass sie eine höhere Wahrscheinlichkeit haben, aufzutreten, und dass sie in der Regel direkt vom Aufrufer der Operation behandelt werden können.
  - Kategorie 2a: Die Operation kann aus bestimmten inhaltlichen Gründen nicht korrekt durchgeführt werden, und muss daher abgebrochen werden. Z.B. hat ein Konto nicht die notwendige Deckung für die Durchführung einer Überweisung.
  - Kategorie 2b: Ungültiger User-Input, z.B. ist ein Eingabewert außerhalb des zulässigen Bereiches oder ein Objekt, auf dass sich die Eingaben beziehen, existiert nicht (mehr).

– Kategorie 2c: Das aufgerufene Objekt hat nicht den notwendigen Zustand, der zum Aufruf der Operation gegeben sein muss.

9.1.2. Fehlerbehandlungs-Ansätze

Fehlerbehandlungsmechanismen, die manchmal auch in Kombination eingesetzt werden:

- *Error codes*: In prozeduralen System-Programmierungs-APIs, wie bei der Linux- oder Windows-API begegnen einem häufig noch error codes, d.h. Operationen liefern üblicherweise error codes als Rückgabewert. Einer der Codes ist häufig mit der Semantik "kein Fehler aufgetreten" belegt. Andere definieren spezielle Fehlersemantiken, die bei Ausführung der Operation aufgetreten sind.

- *Error-Handler*: Manche APIs ermöglichen es, Fehler-Behandlungsroutinen, sogenannte error handler anzugeben, die in Form von Call-Backs von der aufgerufenen Operation gerufen werden, wenn Fehler aufgetreten sind. Ein solcher error handler kann den Fehler dann behandeln.

- *Exceptions*: In objektorientierten Programmen sind Exceptions das Mittel der Wahl für die Fehlerbehandlung. Sie werden von einer Operation geworfen, was die Reihenfolge der Code-Ausführung ändert. Sie können in der call hierarchy gefangen werden. Geschieht dies nicht, beenden sie üblicherweise den Prozess, in dem die Operation ausgeführt werden ist. Fangen entspricht meist der Behandlung des Fehlers. Einge objekt-orientierte Sprachen wie Java und C++ unterscheiden zwischen checked und unchecked Exceptions.

DES 015: Fehlersignalisierung durch Exceptions
`jMeta` nutzt ausschließlich Exceptions als Mechanismus zur Fehlersignalisierung.

Begründung: Exceptions sind in Java gut unterstützt und wohlbekannt. Die anderen oben genannten Mechanismen sind in Java-APIs so gut wie nicht zu finden. Entsprechend ist die Verwendung des De-factor-Standardmechanismus auch für `jMeta` sinnvoll und gut geeignet.

Nachteile: Keine erkennbar

9.1.3. Allgemeine Designentscheidungen zur Fehlerbehandlung

Zunächst eine Designentscheidung mit sehr allgemeinen Richtlinien zu Exception-Klassen:

DES 016: **Richtlinien für die allgemeine Fehlerbehandlung in** `jMeta`
Es gelten folgende Richtlinien in `jMeta`:

- Für jede Fehlerkategorie wird eine separate Exception-Klasse definiert, diese hat einen sinnvollen Namen, der die Fehlerkategorie treffend beschreibt. Dieser Name endet mit "Exception". Die Klasse speichert notwendige Kontextinformationen zur Fehlerursache, die über getter im Rahmen der Fehlerbehandlung abgefragt werden kann.

- `jMeta` wirft keine Exceptions der Java-Standard-Library. Stattdessen werden solche Fehler ggf. in eigene `jMeta` Exceptions als cause gewrappt.

- Generell muss eine `jMeta`-Exception eine verursachende Exception als cause setzen.

- `jMeta`-Exceptions können einen erläuternden Text zur Ursache des Fehlers enthalten. Dieser muss in U.S. Englisch formuliert werden.

Begründung: Fehleranalyse wird somit nicht unnötig erschwert, Exceptions haben eine erkennbare Bedeutung und werden nicht zu generisch.

Nachteile: Keine erkennbar

Die folgende Design-Entscheidung schließt eine Fehlerfassade aus:

DES 017: **Keine Fehlerfassade in** `jMeta`
`jMeta` wird nicht durch eine Fehlerfassade umgeben, die alle unchecked Exceptions abfängt, bevor sie zum Anwender der Library gelangen können.

Begründung: Eine solche Fehlerfassade bedeutet einen zusätzlichen Overhead. Die breite Schnittstelle der Library müsste so an allen "Ausgängen" mit der Fehlerfassade umgeben werden, was die Implementierung unnötig verkompliziert. `jMeta` kann ohnehin nicht alle unchecked Exceptions, die auftreten können, sinnvoll behandeln. Eine Weitergabe an den Anwender ist damit sinnvoll.

Nachteile: Keine erkennbar

Die folgenden Designentscheidungen geben ganz grundlegende an, welche Exception-Arten für welche Fehlerkategorien eingesetzt werden:

DES 018: **Unchecked exceptions für abnormale Ereignisse (Kategorie 1)**
Im Falle von abnormalen Ereignissen wird in `jMeta` entweder eine spezielle `jMeta`-Exception als unchecked Exception (d.h. Exception, die von java.lang.RuntimeException ableitet) geworfen, oder es wird eine durch eine Java-Standard-Library-Methode erzeugte Exception geworfen.
Es wird je Komponente entschieden, welche Fehler als abnormal gelten.

Begründung: Abnormale Ereignisse können vom Aufrufer meist nicht sinnvoll behandelt werden. Durch checked exception würde jedoch zumindest ein "catch" erzwungen. Es macht darüber hinaus außer in Einzelfällen häufig wenig Sinn, runtime exceptions der Java-Standard-Library abzufangen und in `jMeta`-Exceptions zu konvertieren. Dies bringt nicht nur overhead mit sich, sondern gefährdet auch die Portabilität, da unter Umständen unspezifizierte Exceptions gefangen werden.

Nachteile: Keine erkennbar

DES 019: **Checked exceptions für inhaltliche Fehler der Operation (Kategorie 2a)**
Im Falle von inhaltlichen Fehlern einer Operation wird in `jMeta` eine spezielle `jMeta`-Exception als checked Exception (d.h. Exception, die von java.lang.Exception ableitet) geworfen.
Es wird je Komponente und Operation entschieden, welche Fehler als inhaltliche Fehler der Operation gelten.

Begründung: Inhaltliche Fehler einer Operation können erwartet werden. Sie treten häufiger auf als abnormale Ereignisse. Aufrufer wissen i.d.R., wie sie diese behandeln müssen.

Nachteile: Keine erkennbar

> **DES 020:** **Design-by-Contract für fehlerhafte Verwendung einer öffentlichen Operation (Kategorien 2b und 2c)**
> Erfolgen Aufrufe auf öffentliche API-Operationen einer Komponente im falschen Objektzustand (d.h. eine Vorbedingung ist nicht erfüllt) oder werden dort Parameterwerte angegeben, die nicht dem gültigen Wertebereich entsprechen, dann verfährt `jMeta` gemäß design-by-contract rigoros, indem eine spezielle `jMeta` Unchecked Exception geworfen wird und die Verarbeitung der Operation somit ohne Effekt beendet wird. Dies signalisiert, dass es sich um einen fehlerhaften Aufruf der Operation handelt. Dieses Verhalten wird in der Schnittstellenbeschreiung der Methode definiert.
>
> **Begründung:** Der Vertrag ist klar definiert, dem Aufrufe ist klar, was er erfüllen muss, um die Methode verwenden zu dürfen. Falscher Aufruf wird als Programmierfehler gewertet und entsprechend quittiert. Die `jMeta`-Schnittstelle verhindert so, dass fehlerhafte Eingabe zu inkonsistenten Zuständen oder Daten oder zum Propagieren von Fehlern in untere Schichten führen und dann erst später zu, Vorschein kommen, was die Analyse solcher Fehler sehr erschweren kann. Hier wird gemäß "fail fast" gehandelt und der Fehler sofort bei der ersten Möglichkeit erkannt.
>
> **Nachteile:** Keine erkennbar

9.2. Logging in `jMeta`

Logging wird in `jMeta` ebenso verwendet, wie folgende Designentscheidung verrät:

> **DES 021:** **Verwendung von Logging in `jMeta`**
> Logging wird in `jMeta` zumindest in den Subsysteme `Bootstrap` und `Technical Base` verwendet, um Startup der Library zu protokollieren. In anderen Subsystemen wird logging nur in Ausnahmefällen, z.B. bei Fehlerbehandlung eingesetzt. Das Logging kann auf Klassengranularität im Feinheitsgrad vom Anwender konfiguriert oder auch (komplett Klassenübergreifend) deaktiviert werden.
>
> **Begründung:** In hinreichend komplexen Systemen kann Logging zur Fehleranalyse nicht ersetzt werden. Logging ist zumindest für komplexe, fehleranfällige Abläufe unerlässlich. Deaktivierbarkeit verringert die Gefahr von Performance-Problemen.
>
> **Nachteile:** Keine erkennbar

Die Frage ist natürlich, wann und auf welchen Levels genau geloggt wird:

DES 022: **Informative Ausgaben der Library auf INFO-Level, Details auf DEBUG, und Fehler auf ERROR**
Wir loggen folgende Ausgaben auf dem angegeben Level:

- `INFO`: Jegliche Ausgaben, die sich auf die Systemumgebung und die Version der Library beziehen werden einmalig beim ersten Verwenden der Library in der aktuellen JVM geloggt.

- `DEBUG`: Detailausgaben zu Fortschritten bestimmter Startup-Aktivitäten oder auch komplexer Operationen werden bei jedem Aufruf der komplexen Operation geloggt

- `ERROR`: Im Falle von Laufzeitfehlern, die die Library selbst wirft, werden zusätzlich zur Exception Fehlertexte in Englisch auf dem Level ERROR geloggt. Ausnahme: Fehler beim Prüfen von Vorbedingungen, insb. Eingabeparametern führen niemals zu zusätzlichen Logausgaben.

Begründung: Beliebiges unnötiges Loggen wird eingedämmt. Komplexe, ggf. langlaufende Hintergrund-Operationen benötigen detaillierte Informationen für evtl. Fehleranalysen. Bei Laufzeitfehlern der Library selbst soll der Anwender bzw. der Analyst durch entsprechende Details im Logfile darauf hingewiesen werden, dass es an einer bestimmten Stelle ein Problem gegeben hat.

Nachteile: Keine bekannten Nachteile

Zusätzlich muss noch festgelegt werden, ob es eine zentrale Instanz für das Logging gibt, oder ob stattdessen einfach eine Library genutzt wird.

DES 023: **Es wird keine Logging-Komponente erstellt, stattdessen wird slf4j direkt an allen notwendigen Stellen genutzt**

Statt einer dedizierten, eigen-implementierten Logging-Komponente, die jede andere Komponente kennt, für das Logging genutzt wird und intern ein Logging-Framework kapselt, wird slf4j an allen notwendigen Stellen direkt genutzt.

Begründung: Zuerst wurde eine zentrale Logging-Komponente implementiert, die letztlich nur java util Logging verwendet und festdefinierte Formatierungen nutzte. Grundidee war es hierbei, das Logging "wegzukapseln", um Logframeworks austauschbar zu gestalten sowie einige Konfigurationsaufgaben bezüglich des Loggings zu übernehmen. Diese Variante hat sich als wenig sinnvoll erwiesen, aus folgenden Gründen:

- Es muss jeder Komponente auf irgendeinem Wege eine Instanz der Logging Komponente mitgegeben werden bzw. diese muss sich eine Instanz dieser Komponente besorgen, damit können alle Komponenten nur gemeinsam mit der Logging-Komponente wiederverwendet werden

- Soll das Logging für wichtige zentrale Library-Elemente wie `ISimpleComponentRegistry` oder das Verwalten von Erweiterungen genutzt werden, muss es vor deren Initialisierung initialisiert werden, da auch und gerade diese Bestandteile extensiv loggen müssen. Allerdings kann die Logging-Komponente nicht erstellt werden, wenn es noch kein Komponentenframework gibt. Ein Henne-Ei-Problem, was in der Vorversion zu seltsamen und unnötigen Konstrukten geführt hat

- Innovationen im gekapselten Logging-Framework bei Versions-Upgrades erfordern neuen Aufwand in der Logging-Komponente; insgesamt muss die Logging-Komponente entweder alle Funktionen des Logging-Frameworks weitergeben oder diese stark beschnitten anbieten

Die "Kapselung" des Loggings ist ein nur auf den ersten Blick gutes Argument. Erstens sollte man sich fragen: Wie oft tauscht man das Logging-Framework aus? slf4j bietet genau die Austauschbarkeit von Logging-Implementierungen direkt an. Als zusätzliches Plus kann der Anwender von `jMeta` selbst die slf4j-Implementierung seiner Wahl nutzen, was die Library u.a. ideal in bestehende Anwendungen integriert, ohne diesen die Verwendung einer weiteren neuen Log-Library aufzuzwingen. Ausgaben von `jMeta` können so beispielsweise direkt in die Hauptlogdatei der Anwendung mit aufgenommen werden. Zweitens ist Logging an sich "0-Software" ohne anwendungsspezifische Logik, eine eigene Komponente dafür wirkt übertrieben und verkompliziert neben den bereits erwähnten notwendigen Abhängigkeiten die Architektur.

Nachteile: Keine bekannten Nachteile

9.3. Configuration

With the term *configuration* in `jMeta`, we understand the change of specific parameters, which customize the behaviour of `jMeta` at runtime. This is quite vague and the difference to usual specialized setters is unclear.

Thus we want to give some more criteria for configuration:

- Configuration is part of the public API of `jMeta`, i.e. it can be changed by the user.

- It is generic and thus extensible for further releases, i.e. adding new configuration parameters means to add a new constant to the API and update the documentation; the API for setting and retrieving the configuration parameter - as it is generic - does not change by adding new, changing existing or removing old parameters

- Configuration parameters usually have global effect and usually are just used once; but, of course in theory we could also make them dynamically changeable by users at runtime, and their scope could also be limited, e.g. to individual media

For now it turned out that there is no need in `jMeta` for such dynamic configuration parameters a.k.a properties, neither globally, nor for individual components. We thus summarize as follows:

> ***DES 024:*** `jMeta` **offers no generic mechanism for (global or local) configuration, especiall it currently defines no properties that influence the behaviour of the library**
> All necessary "configurations" for customizing the behaviour of a component are passed by the user via specialized (i.e. non-generic) setters or constructor parameters.
>
> **Begründung:** There is no need for the bigger flexibility yet.
>
> **Nachteile:** No disadvantages known.

9.4. Naming Conventions and Project Structure

9.4.1. Java Naming Conventions

We use the standard Java naming and formatting conventions as defined by Sun. Only small addition: If there is a service interface with only one implementation, this implementation is having the prefix `Standard`. E.g. the default implementation for the `MediumStore` interface is named `StandardMediumStore`.

9.4.2. Package Naming Conventions

Here, we quickly define the package naming to be used for the library and extensions of the library.

Core Library

All packages for the core library start with `com.github.jmeta`, according to the Java naming conventions. The reason is that the library is hosted on Github. Below this core name, the following sub-packages are used:

- `.library.<component>` for all core components of the library, where "`<component>`" is replaced by the actual component name

- `.utility.<component>` for all technical utility code needed for the library, where "`<component>`" is replaced by the actual category name

- `.defaultextensions.<extension name>` for all extensions delivered by default bundled with `jMeta`, where "`<extension name>`" is the name of the extension, usually a single data format name; see also the next section for third-party extensions

Below these package names, there is another hierarchy:

- `.api` containing the public interface of the component, utility or extension; this package itself should not contain classes directly, but is further subdivided into:
    - `.services` containing the function interfaces the user needs to use to work with the component, utility or extension
    - `.types` containing any transport objects, data types or the like for the component, utility or extension
    - `.exceptions` containing any public exceptions of the component, utility or extension

- `.impl` containing the private implementation of the component, utility or extension; sub-divisions into further packages below it are possible, but component-specific and not standardized

Extensions

As mentioned already, the default extensions delivered together with `jMeta` of course also use a package naming convention quite similar to the core library package names. For any third party extensions, there is of course no definition of how the packages should be named, but it is up to the creators of the extension.

However, extension providers should follow the standard Java package naming conventions, and they should ensure that their package names do not clash with package names of other `jMeta` extensions.

9.4.3. Project Naming and Structure

Every IDE project containing code for `jMeta` starts has the form `jMeta<LibraryPart>[Extension]`, where `<LibraryPart>` is:

- `Library`: The core library with the main user API, without any extension specific parts

- `Utility`: Any utility the core library and extensions need, but no classes the library user must depend on, i.e. just internal library utility

- `DefaultExtension`: For all projects building an extension that is already bundled by default with the core library.

- `Tools`: For any supporting, development or testing tools, i.e. mostly Java applications that can either be used by library users or by library developers

- `Docs`: For any documentation of the library, no source code here (except for docs, e.g. tex files)

`[Extension]` is only used for the `DefaultExtension` library part. Each extensíon needs its own project and build unit. The reason is requirement "**?? ??**". This allows us to depoly individual JARs for each single extension.

Below, you can see the actual projects currently existing and their allowed dependencies: TODO

9.4.4. Build Module Structure and Dependencies

The Maven build module structure is of course aligned with the project structure: There is exactly one Maven module per project, having the same dependencies as depicted above. One exception might be the Docs project as it contains no sources. In addition, there is a single parent POM for general dependencies and aggregate builds.

10. Subsystem `Technical Base`

10.1. `Utility` **Design**

In diesem Abschnitt wird das Design der Komponente `Utility` beschrieben. Grundaufgabe der Komponente ist das Anbieten genereller Querschnittsfunktionalität, die unabhängig von der Fachlichkeit ist, und so potentiell in mehreren Projekten Verwendung finden kann. Hier werden allerdings nur diejenigen Aspekte beschrieben, die für `jMeta` relevant sind.

10.2. `ComponentRegistry` **Design**

In this section, the design of the component `ComponentRegistry` is described. Basic task of this component is the implementation of design decisions DES 024 and DES 024.

We just give the basic design decisions here. Before the current solution, we used a relatively complex custom-made component mechanism with caching, XML configuration of interface and implementation as well as registration of the components at startup. This code was organized in an eclipse project named "ComponentRegistry", but was later a bit simplified later as "SimpleComponentRegistry". However, after realizing that the built-in Java SE `ServiceLoader` mechanism is fully suitable and even better than the "SimpleComponentRegistry", this mechanism is used now.

According to DES 024, a component is a "Singleton". However, its life cycle must also be clearly:

> **DES 025:** `ComponentRegistry` **uses Java's** `ServiceLoader` **mechanism**
> `ComponentRegistry` uses Java's `ServiceLoader` class to load the
> implementation for a given component interface. All component interfaces and
> their implementations need to be configured in META-INF configuration files as
> indicated by the Javadocs of `ServiceLoader`.
>
> **Begründung:** The `ServiceLoader` mechanism is quite easy to setup and
> requires nearly no specific coding. No code needs to be written to read
> corresponding configuration. A specific description / documentation mechanism
> of each component at runtime is not necessary, thus it was omitted (in contrast
> to previous implementation).
>
> **Nachteile:** Of course, `ServiceLoader` has its limitations: You might not be
> easily able to add components at runtime without writing additional code or not
> at all. And it does not have any idea of the term of a component, it just knows
> interfaces and implementations. But this is all not a requirement for `jMeta`.

Here is just a short summary of small amount the self-written code in `ComponentRegistry`:

> ***DES 026:*** `ComponentRegistry` **consists of a single non-thread-safe class for looking up implementations and cache handling**
> `ComponentRegistry` solely consist of a single class. This class caches `ServiceLoader`s. It offers the following methods:
>
> - `lookupService`: Loads a service implementation (if called the first time for an interface) and returns it, adds its `ServiceLoader` to the cache afterwards
>
> - `clearServiceCache`: Clears the internal cache of `ServiceLoader`s such that the next call re-reads and re-instantiates new implementations again.
>
> The class offers this as static methods, but it is not thread-safe.
>
> **Begründung:** Why do we cache `ServiceLoader`s? Because the `ServiceLoader.load` method always creates a new instance of the `ServiceLoader` class, which has the following effects:
>
> - Components are singletons, thus, if two different other components need an implementation of the component at different points in time, they would get different instance of the service implementation, as they would always create a new `ServiceLoader` instance.
>
> - `ServiceLoader.load` does file I/O, which is not what we want every time we request a new implementation.
>
> The method `clearServiceCache` is necessary for test cases which might need to reset the `ComponentRegistry` state after each test case. As it is a static class, this method is necessary.
> Why static methods? Because we do not want to care about instantiating it, passing the same instance everywhere needed.
> Why is it not thread-safe? Because the whole library is not intending to the thread-safe.
>
> **Nachteile:** No disadvantages known

10.3. `ExtensionManagement` Design

This section describes the most important design decisions for the technical helper component `ExtensionManagement`. The main task of this component is discovery of extensions and to make their interfaces available to the whole library, preferably in a very generic way.

In the first version of this components, extensions were loaded by a relatively complex `URLClassLoader` approach and used a main and an extension-specific XML configuration file. However, this was more complex than necessary, thus we define here a more lightweight approach:

> **DES 027:** **Extensions are discovered and loaded at library startup directly from the class path, no dynamic loading of extensions is required**
>
> When the library is first used in a Java application, it scans the class path for any available extensions. The extensions that are available at that time are available for further use. There is no possibility for the user itself to add extensions. Furthermore, it is not possible to add, exchange or update extensions at runtime in any way.
>
> **Begründung:** It is quite convenient for users to simply put extension onto the class path, e.g. using Maven or Gradle, and it is auto-detected. This fulfills the requirement "**?? ??**". Dynamic loading or updating of extensions automatically or triggered by the `jMeta` user is not necessary, as in most use cases it should be clear at compile-time which extensions are required. As extensions should not be introducing a big overhead, applications can easily provide all in total possible extensions at build-time already.
> Last but not least, for the `jMeta` implementation, complexity is largely reduced if we omit the requirement to load, update or exchange extensions at runtime.
>
> **Nachteile:** No disadvantages known

How does the library identify extensions on the class path?

> **DES 028:** **An extension is identified by implementing `IExtension` and being configured by the `ServiceLoader` facility**
>
> An extensions is identified by each implementation of the `IExtension` interface that is configured in a JAR file on the class path as a service provider. It is found on the class path by the library core by using the Java `ServiceLoader` class. It does not matter if the extensions is located in a separate JAR file or even already in the core, and how much extensions are in a single JAR file.
>
> **Begründung:** `ServiceLoader` is a quite convenient and very easy to use mechanism.
>
> **Nachteile:** No disadvantages known

Regarding the configuration of extensions:

> **DES 029:** **There is no central configuration file listing available extensions; extensions themselves use code to provide a description of the extension and no config files**
> Extensions are just discovered via classpath. There is no central configuration file listing all available extensions for the `jMeta` core. Furthermore, extensions themselves might provide a description, but this description is also not contained in a configuration file, but rather returned by the `IExtension` implementation directly in Java code.
>
> **Begründung:** A central configuration of all available extensiosn for the `jMeta` core would be very inflexible. It would need to be extended anytime a new extension is available. And then, by whom? The end user, the developers of the extensions or even the `jMeta` developers? This would not make much sense. For the extension specific details, a configuration file could be used, but it again makes it harder to create an extension and we would need additional generic code to parse the configurations. Configurabilty for such things is not necessary at all. If a change in the description is necessary, it would be related to changes in the extension anyway and the JAR for the extension can be updated to have the updated description. An XML file embedded in the JAR file would not bring any differences or even advantages.
>
> **Nachteile:** No disadvantages known

Which functional interfaces do extensions provide in which way?

> **DES 030:** **Extensions can be queried dynamically by the library core to provide 0 to N implementations for an arbitrary Java interface**
> `ExtensionManagement` provides a generic method in `IExtension` where `jMeta` core components can get all implementations of any Java interface they request which are provided by the extension. The extension of course might not have such implementations. But it might also have more than one implementation.
>
> **Begründung:** Although in section "8.2 Extensions", specific cases for the extensibility of `jMeta` were mentioned, we do not want to hard-wire this into a generic component such as `ExtensionManagement`. If we would do this, there would be most probably a cyclic dependency from `ExtensionManagement` to these components of the `jMeta` core that are extensible and thus need to load extensions.
> Furthermore, we do not need to change the interface of `ExtensionManagement` whenever extensions might need to return implementations for any other interfaces that can be extended in future.
>
> **Nachteile:** No disadvantages known

What is the lifecycle of an extension, then, and is there anything else they should do?

> **DES 031: An extension is instantiated just once and then used throughout the whole application, offering a method to retrieve implementations**
>
> According to DES 031, an extension is loaded at `jMeta` startup. It can be considered as singleton, as just a single instance of it is loaded using `ServiceLoader`. Extensions should have the sole purpose of returning new implementation instances, for which they implement the method `IExtension.getExtensionProviders`. Anytime this method is called, they provide a list of new implementations they provide for the given interface. If they do not provide an implementation, they return an empty list. Besides that, there is a method `getExtensionDescription` where extensions can provide additional detail information for the extension.
> Extensions should not do anything else. Especially, they should not have any internal mutable state or perform any background processing.
>
> **Begründung:** There is no reason why extension providers should implement any special behaviour in addition to just returning implementations to use by the core, except, maybe harmful hacking code.
> Of course, `jMeta` cannot really prevent that, but at least it should be made clear.
>
> **Nachteile:** No disadvantages known

We should now go into more detail how the library core interacts with extensions. So far, we defined that extensions will be loaded once at startup using the `ServiceLoader` facility. But what is the public interface of the `ExtensionManagement` component?

> **DES 032: `ExtensionManagement` provides the interface `IExtensionsManagement` which provides access to all extensions found**
> `ExtensionManagement` provides the interface `IExtensionsManagement` for the library core with the method `getAllExtensions`. This method returns all available `IExtension` implementations found.
>
> **Begründung:** An easy to use `ExtensionManagement` without any surprises.
>
> **Nachteile:** No disadvantages known

11. Subsystem `Container API`

11.1. `Media` Design

In this section, the design of the component `Media` is described. Basic task of the component is to provide access to memory areas which contain multimedia data. Primarily these are files.

The term MEDIUM needs to be sharpened here: In "3.6 MEDIUM" we had defined: "A MEDIUM defines the storage medium of DATABLOCKS. It can be a file or a MEDIA STREAM, or the main memory itself."

In detail, the term summarizes the aspects "physical storage" and "access mechanism" (e.g. file-based random-access, or byte stream). Thus there might perfectly be two different media which access the same physical storage, but using different access mechanism. The term MEDIUM is an abstraction and potentially allows even more special possibilities, like media streams, databases etc.

11.1.1. Basic Design Decisions `Media`

Here, the fundamental design decisions of the component `Media` beschrieben.

Supported Media

This section lists decisions about supported MEDIA. To start with, it is clear that `jMeta` must support files as basic medium.

DES 033: Support for random-access file access
`jMeta` supports the use of files as input and output medium via `Media` with access mechanism "Random Access".

Begründung: Files are *the* fundamental and most common digital media containers, even in 2016. Of course MP3 files, AVI files etc. with multimedia content are wide-spread. A library such as `jMeta` must support files as core element. To more efficiently process files, random-access is inevitable. Especially reading at arbitrary offsets - e.g. tags at end of file - as well as skipping of unimportant content is efficient to implement with random-access.

Nachteile: No disadvantages known

But also reading streams shall be supported to increase the flexibility of the library:

> ***DES 034:*** **Support for sequential, reading byte streams**
> `jMeta` supports the use of reading byte streams, i.e. `InputStream`s for input in mode "sequential access".
>
> **Begründung:** `InputStream` represents the most general alternative of a MEDIUM from Java perspective, which ensures a potentially higher flexibility for using `jMeta`. E.g. multimedia files can be read from ZIP or JAR archives using streams, and support for media streams might be easier to implement in later releases - However: To state clearly: media streams do have nothing to do with this design decision. They might be implemented completely different in upcoming releases.
>
> **Nachteile:** An `InputStream` supports by definition only sequential access and no random-access (e.g. via `FileInputStream`). Thus there might be higher complexity for implementation, as well as signficant performance drawbacks because of lacking random-access.

Last but not least, the library offers access to RAM contained data, due to flexibility:

> ***DES 035:*** **Support for random-access to byte arrays**
> `jMeta` allows for random-access to byte arrays as input medium and output medium.
>
> **Begründung:** Already loaded memory content can be parsed with `jMeta` without need for artistic climbs, increasing flexibility of the library.
>
> **Nachteile:** No disadvantages known

What about `OutputStream`s? That is discussed in the following:

> ***DES 036:*** **No support for writing byte streams**
> `jMeta` does not support writing byte streams, i.e. `OutputStream`s.
>
> **Begründung:** `OutputStream`s are write-only, but still not random-access. Thus we would need - provided we want to access random-access media in a random-access style - a second implementation next to writing random-access. A combined usage of `InputStream`s and `OutputStream`s for Read-/Write access on the same medium is not designed into the Java API and leads to diverse problems. As `jMeta` already implements writing to output files and byte arrays, for reasons of effort, `OutputStream`s are not supported as output media. The user might implement `OutputStream`s easily by him- or herself, e.g. by first writing into byte arrays, then into an `OutputStream`.
>
> **Nachteile:** No disadvantages known

Consistency of Medium Accesses

Parallel access to the same medium from different processes or threads, reading by one and writing by the other, might lead to unpredictable difficulties - even without using any caching. If you e.g. have some parsing metadata like the length of a block in bytes at hand, but a parallel process shortens the block, your read access trying to fetch the whole block will run into unexpected end of file or read inconsistent data.

To avoid such problems, there are special locking mechanisms for exclusive access to the bottleneck ressource, at least for files. We define:

DES 037: Locking of files during jMeta **access**
Files are *always* locked during access by jMeta explicitly. File content is protected by exclusive locks from corruption by other processes and threads. See [PWikIO], where we show that a file in Java must be explicitly opened for writing to be able to lock it. "During access" means: After opening it and until closing it. The lock thus might be long-term. jMeta opens a file for writing (and locking) even if the user explicitly requested read access only.

Begründung: Other processes and threads of the same JVM cannot access the files and corrupt any data, which avoids consistency problems.

Nachteile: It is not possible to access the same file in parallel threads when using jMeta. It seems rather unlikely that such parallel access to the same file (e.g. reading at different places) can speedup an application. But for future media this might indeed be a drawback.

The locking of byte streams or memory regions does not make sense, as discussed in the following desing decisions:

DES 038: No locking of byte streams
Byte streams are not locked

Begründung: The interface InputStream does not offer any locking mechanisms. jMeta will not try to guess the kind of stream and lock it (e.g. by checking if it is a FileInputStream).

Nachteile: No disadvantages known

For different processes, the os usually protects access of memory regions. The question is whether jMeta should protect access to byte arrays:

> ### *DES 039:* **No locking of byte arrays**
> Byte arrays are not locked
>
> **Begründung:** This makes not much sense as the user anyways gets a reference to the byte array by the API, and thus can access and manipulate the raw bytes arbitrarily in a multi- or single-threaded way. Protecting it by thread locking mechanisms increases complexity and does not seem to generate any benefits whatsoever.
>
> **Nachteile:** No disadvantages known

Unified API for Media Access

In the wiki article [PWikIO], we have shown clearly the differences between byte streams and random-access files. With so many difference the question arises: Can this be unified at all and does the effort make sense here? The least common demoninator for random-file-access and `InputStream`s is the linear reading of all bytes in the medium. This is clearly too less. It denies all advantages of random-access. The intersection of features for a unification is therefore not making sense.

Moreover, we want a unifying combination of both approaches:

DES 040: **Unified access to all supported media types in one API**
`Media` offers a common abstraction for accessing files via random-access,
`InputStream`s as well as byte arrays. This API provides the advantages of both
access mechanisms via a common interface. The implementation throws
exceptions of kind "Operation not supported" in some cases, if a feature is not
supported by the medium. In other cases, a meaningful alternative behaviour is
implemented. The using code must perform branche decisions at some places
depending on the medium type.
While byte arrays are no problem for the abstraction, even random-access files
and `InputStream`s have more in common as you might think at first glance:

- The operations Open, (sequential) Read, Close.

- `InputStream`s can also (at least technically) be assigned a beginning,
  offsets and an end.

- Files can be read-only, too, which `InputStream`s are always by definition.

Writing access to a read-only medium is acquitted with a runtime exception,
especially for an `InputStream`.
The main difference between files and `InputStream`s is of course: Random access
is possible for files, while `InputStream`s can only be read sequentially. This
difference can be potentially decreased using mechanisms such as buffering.

Begründung: The API of the component `Media` gets easier for outside users,
its usage feels more comfortable. Using components of `Media` can offer their
users in turn an easier interface. At the same time, the advantages of both
approaches (random-access and better performance for files, generality and
flexibility for streams) are still available.

Nachteile: A few operations of the API cannot be implemted for both media
types, which makes case decisions in the client code necessary in some cases.

Two-Stage Write Protocol

When Writing, it is all about bundeling accesses and buffering. We want optimum
performance und thus want to implement these mechanisms. Therefore we commit
to following design decisionfor implementing writing in `jMeta` in general:

> ***DES 041:*** `Media` **uses a two-stage write protocol controlled by the user**
> The first stageis the mere registration of changes, that need to written to the external medium. In this first stage, there is no access to the external medium yet. The second stage is the operation *flush*, the final writing and commiting of all changes to the external medium. The underlying implementation bundles the write actions according to its needs into one or several packets and execute the write only in the second stage.
>
> **Begründung:** An efficient write implementation is possible. Internally, write actions can be bundled as needed to perform better. And this can be done without forcing the user to do it himself. The user can perform write (registration) actions whenever his code architecture needs it. Saying this, the user code is not burdened with too much restrictions or rules. Furthermore, the potential possibility of an "undo" of already registered actions comes into view.
>
> **Nachteile:** Errors that occur when actually flushing changes to the external medium are recognizes potentially quite late. Thus the registration of changes is quite fast while the flush itself can be a long taking process. Bugs might be introduced by user code forgetting to implement the second step, the flush.

Even if we implement this, it must be clearly stated that this is not in any way a transaction protocol as implemented by some O/R mappers (e.g. hibernate) or application servers. The mentioned protocol is much simpler and not in the least capable to provide ACID! Thus the following exclusion:

> ***DES 042:*** **Writing in** `Media` **does not guarantee ACID, in case of errors during** *flush*, **there is no rollback**
> ACID (atomicity, consistency, isolation and durability) is not ensured neither by the implementation ofn `Media` nor in gerenal by the Java File I/O. If e.g. an error occurs during Writing in the *flush* stage, some data has been written already, while upcoming data will not get written anymore. There is no undo of already written data. The operation *undo* must not be mixed up with a rollback and it is no action that is done automatically. While isolation and durability can be more or less provided, the user is responsible for consistency and atomicity himself.
>
> **Begründung:** A transaction manager that guarantees ACID, and this for files, is really hard to implement (correctly). This requirement is somehow out of scope, no other competing library is doing something similar. `jMeta` will not be a database!
>
> **Nachteile:** No disadvantages known

Requirements for the Two-Stage Write Protocol

Which writing operations must be offered? One method write() - at the end it is the only really writing primitive of the Java File I/O - is not sufficient. How do you remove with this method? write() equals *overwriting*, which means you have to do a lot of manual work to implement insertion, removal and replacement with this operation, it is not convenient at all. `Media` must offer a better API, taken some of the burdens of I/O from the user. Here, we only specify the necessary operations, without going into details with their implementation - this will be done later.

To develop a good design, however, you must first list down the user's requirements to `Media`. This especially includes the requirements for a two-stage write protocol. Main users of the component is definitely the component `DataBlocks`. It uses `Media` to extract and write metadata from and into tags. Without going into the design details of `DataBlocks`, here we nevertheless list detailed requirements that `DataBlocks` has for `Media` regarding two-stage writing, see table 11.1.

ID	Requirement	Motivation
AMed01	It must be possible to insert bytes	Formats such as ID3v2 can be dynamically extended and have a payload of flexible length. Before an already present data block, it must be possible to insert another one. There is especially a need for an insertion operation in the case when metadata with dynamic length need to be written at the beginning of a file.
AMed02	It must be possible to remove bytes	With the same motivation as for insertion. It must be especially possible to remove entire metadata tags.
AMed03	It must be possible to replace bytes and not only overwrite, but also grow or shrink an existing byte area with replacement bytes	In metadata formats, there are both static fields with fixed length as well as dynamic fields such as null-terminated strings. If bytes are already present, it must be possible to overwrite them to save costly remove and insert operations. The growing and shrinking is especially useful and represents a higher level of abstration. If this would not be possible, replacing a previous small string value by a new longer or shorte one would need to be implemented with two operations (overwrite and insert or remove, respectively).
AMed04	Inserted data (requirement AMed01) must be changeable before a `flush` e.g. by extending, overwriting or removing of child fields inside the inserted data block	Based on the two-stage write protocol, an arbitrary number of writing changes can be made before a `flush`, and these might correct each other. E.g. a new ID3v2 tag footer is inserted, that stores the length of the tag. Assume that after this, a new frame is inserted into the tag, before the flush. This requires the `size` field in the firstly inserted footer to be changed afterwards again, before the flush.

ID	Requirement	Motivation
AMed05	Replaced data (requirement AMed03) must be changeable before a flush e.g. by extending, overwriting or removing of child fields inside the replaced data block	A prominent example is insertion of and step-by-step extension of a frame into an ID3v2 tag: For the first creation as well as each extension, the size field of the tag must be changed, which induces a replace operation each time. E.g. it is allowed that users first only create and insert the new frame, and then insert new child fields afterwards, step by step.
AMed06	The padding feature of several data formats should be used by jMeta	Formats such as ID3v2 allow padding, i.e. using an overwrite buffer are to avoid newly writing the whole file. jMeta must use this feature when writing data, such that e.g. an insert only affects the file content until the padding area, effectively decreasing the padding, while a remove increases the padding, but the overall tag size remains the same. It is rather an indirect requirement which needs not necessarily be implemented by Media only.
AMed07	The operations replace, remove and insert must be undoable before a flush	This allows to avoid unnecessary accesses to the medium and to undo mistakes by end users.
AMed08	It must be possible to insert multiple consecutive blocks of data	E.g. you want to add an APEv2 tag first, then an ID3v2.3 tag and then an ID3v1 tag.

ID	Requirement	Motivation
`AMed09`	It must be possible to insert a block of data before an existing block, then replace or remove this existing block with something else; the same must be possible for first remove or replace, then insert (i.e., the inverse order)	E.g. you want to add an APEv2 tag first, then replace the follow-up, already existing ID3v1 tag with some different content.
`AMed10`	It must be possible to modify (remove, insert, replace) a block of data, then remove an enclosing block of data	E.g. the code flow first decides it is necessary to add a new frame to an existing ID3v2.3 tag, modify some of its frames, remove another one; but then due to some decision in the code, it becomes necessary to remove the entire tag.
`AMed11`	It must be possible to modify (remove, insert, replace) a block of data, then replace an enclosing block of data	E.g. the code flow first decides it is necessary to add a new frame to an existing ID3v2.3 tag, modify some of its frames, remove another one; but then due to some decision in the code, it becomes necessary to replace the entire tag with different content.
`AMed12`	Except `AMed10`, `Media` does not need to support overlapping removes or replaces	Data blocks are never overlapping, except `AMed10`, there is no such case that you remove a block, then remove an overlapping portion of it.
`AMed13`	`Media` does not need to support modifications (remove, insert, replace) within an already removed or replaced block of data	It is not clear how to treat changes in an already removed or replaced parent object consistently, so we just reject them.

Table 11.1.: Requirements for the two-stage write protocol by `DataBlocks`

Based on these requirements, we can first define the following basic design decisions for writing:

DES 043: Media **offers the writing operations** *insert*, *remove* **and** *replace*

The user can:

- *insert* N bytes at a given offset (adresses requirement AMed01)

- *remove* N bytes at a given offset (adresses requirement AMed02)

- *replace* N bytes at a given offset by M new bytes (adresses requirement AMed03). Thus, replace has three flavors:

  1. replace N bytes by $M > N$ new bytes actually behaves like an insertion, replacing the first N bytes with new ones, and inserting additional $M - N$ bytes behind. We call it an *inserting replace*.

  2. replace N bytes by $M < N$ new bytes actually behaves like a removal, replacing the first M bytes with new ones, and removing additional $N - M$ existing bytes behind. We call it a *removing replace*.

  3. replace N bytes by $M = N$ new bytes actually behaves like a usual write. We call it an *overwriting replace*.

Begründung: See requirements AMed01, AMed02 and AMed03. The burden to implemen these convenient operations using the Java File I/O, which essentially only offers write() and truncate(), is taken over by Media, such that the user need not care.

Nachteile: No disadvantages known

How is the padding requirement adressed? Like this:

> ***DES 044:*** **Requirement `AMed06` must be adressed by components using `Media`, it is not built into `Media` itself**
> `Media` does not implement `AMed06` itself, it does not know something like "Padding", but just the three primitive change operations. Using them, a third party component can do the following using `Media`:
>
> - If a new field is added to the ID3v2 tag (with an *insert*) and padding that is longer than the newly inserted content is present, the 3rd party component has to do a `remove` of a corresponding number of padding bytes, or a `replace` of old padding bytes by new (shorter) padding bytes.
>
> - If a field is removed from the ID3v2 tag (with a *remove*), the 3rd party component can do an `insert` of a corresponding number of padding bytes at the end of the tag, or a `replace` of old padding bytes (if present) by new (longer) padding bytes.
>
> **Begründung:** `Media` should stay clean of any "functional" terms defined by some formats, but it should just stick to the primitives it offers to modify media content. As shown above, the requirement can quite easily be implemented by tag-specific logic on top of `Media`.
>
> **Nachteile:** No disadvantages known

As we have a two-stage write protocol, the *undo* of not yet flushed changes is possible, and according to the requirements also necessary.

> ***DES 045:*** **Writing operations on a medium can be undone with *undo* before a *flush*, adressing requirement `AMed07`**
> Writing operations lead to pending changes according to DES 045. These can be undone according to the requirements defined above.
>
> **Begründung:** The application logic can require *undo* in some cases, e.g. for corrections of mistakes done by an end user. Instead of requiring to call the inverse operation (if any at all), the user is much more convenient with undoing the operation itself directly. This also ensures that the using code does not need to trace changes to be able to find which is the inverse operation.
>
> **Nachteile:** No disadvantages known

This leaves open `AMed04` and `AMed05` as well as `AMed08` to `AMed13` which we will adress later when discussing the details of the two-stage write protocol.

Caching

The component `Media` takes over I/O tasks with potentially slow input and output media. Thus, it is here where the basic performance problems of the whole library need to be solved. We will approach these topics with some motivation and

deductions.

In [PWikIO], basic stuff regarding performance with file access is discussed. The ground rule for performant I/O is minimizing accesses to the external, potentially slow medium. For writing, we already introduced DES 045. A similar important question is: How can you make reading perform better?

At first it is quite clear that for reading, you should help yourself with buffering to improve performance:

> **DES 046: Reading access can be done using a buffering mechanism, controlled by the component's user**
> For each reading access, the calling code can specify the number of bytes to read, which corresponds to a buffering. The code controls the size of the buffer by itself. It potentially can also read only one byte. It lies in the responsibility of the calling code to read an amount of bytes that makes sense and minimizes read accesses.
>
> **Begründung:** A hardcoded fixed length buffering would rather lead to performance disadvantages, as there might be read too much bytes, more than necessary in average. Furthermore, depending on the fixed size, it would be necessary to read two or even several times when a bigger chunk of data is needed. According to [PWikIO], there is no "one size fits all" for buffer sizes in file I/O. The logical consequence is to let the user decide.
>
> **Nachteile:** No disadvantages known.

A further important aspect is caching: With *Caching*, we refer to the possibly long-term storage of MEDIUM contents in RAM to support faster access to the data. Buffering differs from caching in a sense that buffering is only a short-lived temporary storage without the necessity of synchronisation.

To start with, we can see - besides the already mentioned buffering - different kinds of "Caching" in an application that is based on `jMeta`:

- During file access there are caches on hardware level, in the OS and file system.

- Java supports temporary buffering via the `BufferedInputStream`, and caching explicitly via `MappedByteBuffer`s.

- Applications that mostly are interested in human-readable metadata read it, convert it via `jMeta` into a clear-text representation and show this representation in their GUI. In this case the GUI model represents a kind of caching that also allows changes to this metadata in the GUI, it is not necessary to re-read again from the medium.

If we look at all these alternatives, the question arises why at all an additional built-in caching in `jMeta` would be needed? For answering this question, we should look at some use case scenarios for the library: One scenario is the already mentioned reading of metadata from a file to display it in a GUI. For such a case,

caching would usually not be very useful. You read once, and maybe twice, if the user wishes to update the screen. It would be an acceptable performance without caching. Another use case is the arbitrary jumping between parts of a container format file using a low-level API to process specific contents. This is true "random access". The question is: Do you want to read the same place twice? Sometimes possibly yes. Instead, would you want a direct medium access again? Possibly yes or no.

The last question brings up another general problem with caching: The problem of synchronicity with the external medium. If the medium has been changed in between, the cache content is probably aged and invalid. Code that accesses the cache can usually not recognize this.

We first sum up the identified advantages and disadvantages:

Advantages	Disadvantages
+ Performance improvement when reading the same data multiple times, as cache access is much faster than the access to the external medium	− When only accessing once there is of course no performance improvement
+ In a cache you are - in principle - more flexible to reorganize data than on an external medium, making it easier to correct, undo or bundle changes.	− External 3rd party changes on the MEDIUM cannot be recognized and lead to invalid cache content that might lead to erroneous behaviour or data corruption in follow-up write actions.
	− There is additional code necessary for caching, e.g. questions such as "when is the allocated memory freed?" must be answered. For consistency topics, even more complex code is necessary.
	− More heap space required

Table 11.2.: Advantages and disadvantages of caching in `jMeta`

The disadvantages outweight the advantages. Why should you then use caching in `jMeta` at all? Because some of the previous design decisions combine well with a caching approach:

- DES 046 can be achieved using a cache, as we see just a little later

- DES 046 can be implemented with a cache, i.e. anything that has been buffered should directly go into the cache for subsequent read actions

- DES 046 may or may not be easier to implement using a cache. In this case the cache would be used to store the registered changes before a flush. However, if it would only be this, a cache would be greatly too complex. Easier solutions are possible for holding the not-yet-flushed data.

Thus we decide:

DES 047: `Media` **keeps medium data read in a cache**
`Media` uses a RAM-based, potentially long-lived fast storage (cache) to store already read content of the MEDIUM. Subsequent read accesses request the cache content (if present) only.

Begründung:

- We provide faster repeated read access to already read data to the end-user

- This can be used for direct implementation of DES 047 in a sense of buffering when reading. i.e. the cache works as the buffer for DES 047

- Implementation of DES 047 can be done using a cache

Nachteile: Were given in table 11.2. The alternative is a direct medium access. To summarize the disadvantages against a direct medium access:

- Higher code complexity

- More heap required, the cache is durable

- The medium might change by external processes, such that the cache content is not in synch anymore.

Note that this last mentioned disadvantage is mostly mitigated by DES 047.

How to use caching to better achieve DES 047?

> *DES 048:* **Caching is used to better mitigate the differences between `InputStreams` and files according to DES 048.**
> The data that has been read from an `InputStream` is always put into a cache. Reading actions are therefore allowed to "go back" to already read data, by not issuing another direct access (which is anyway not possible using an `InputStream`), but by taking the data from the cache. "Read ahead" for areas that have not yet been reached on the `InputStream` lead to the behaviour that all data up to the given higher offset is read and cached.
>
> **Begründung:** This implements DES 048 nearly entirely, "transparent" to the user.
>
> **Nachteile:** Even more heap space is necessary for `InputStream`s, as in extreme cases the whole medium might end up in the cache, which might lead to `OutOfMemoryError`s.

Of course, the disadvantages mentioned in DES 048 are heavy-weigth. If you wouldn't do anything about it to mitigate these disadvantages, then DES 048 would be nonsense, as the advantages of this approach would be dramatically overshadowed by its disadvantages.

As a first step, the following three design decisions are necessary:

> *DES 049:* **The user can disable caching entirely**
> The user can disable caching entirely. Here, too, access to previously cached offsets is not possible for `InputStream`s and will be acquitted with an exception.
>
> **Begründung:** The user is responsible to decide about the memory footprint: E.g. if the medium is comparatively small, caching can be tolerated. If it is a big medium, the user has the possibility to disable caching, however demanding a step-wise processing of the data.
>
> **Nachteile:** The implementation of `Media` gets more complex due to corresponding case decisions.

DES 050: **The user can set the maximum size of the cache per medium, the cache keeps only the newest added data**
The user is allowed to limit the maximum size of the cache per medium by configuring it before creating the cache. The cache implementation ensures that at any time, the cache does not contain more bytes than which correspond to the maximum size. This is done using a FIFO (first in, first out) mechanism. I.e. the bytes added first are first discarded whenever trying to add new bytes to a cache.

Begründung: This way, the user can influence the maximum heap size required for caching of a single medium. At the same time, he needs not control the cache size himself, but it is internally managed by `Media`

Nachteile: .

No disadvantages known

DES 051: **Performance drawbacks of `InputStreams` are explicitly documented**
Reducing differences between `InputStream`s and files by caching in accordance to DES 051 means: You must deal with the fact that you cannot store virtually unlimited `InputStreams` in a cache. For file access, the user can also choose between `FileInputStream` and more direct access via `RandomAccessFile`s. The performance drawbacks induced by using `FileInputStream` compared to random-access - which are introduced by a unified API according to DES 051 - are explicity described in the `jMeta` documentation. The mitigation mechanisms (setting maximum cache size, disabling caching) are explicitly described with their corresponding consequences.

Begründung: There are no wrong expectations by providing the unified API. The contract is described clearly enoughto the user. He must choose the medium best suited for his purpose.

Nachteile: No disadvantages known

DES 052: **The user cannot free up cache data in a fine-grained way**
`Media` will not provide any mechanisms for the user to free up cached data himself in a fine-grained way (e.g. range-based).

Begründung: This functionality needs to be implemented and tested (additional effort). It is quite unlikely that it is actually needed when having implemented DES 052. Furthermore, when should the user free the data? A monitoring by the using code is necessary which also makes the using code more complex.

Nachteile: No disadvantages known

After these results, the disadvantages previously listed in table 11.2 and in DES 052 need a closing look:

- Code Complexity: The higher code complexity cannot be disregarded. You have to accept it when implementing a permanent caching. It implies you need very good unit and integration tests to ensure it works as expected.

- More Heap Memory: It is usual to achieve a better runtime performance by increasing the memory footprint. So it is here. To nevertheless avoid `OutOfMemoryError`s, we have defined DES 052 and DES 052 and thus give enough room for the user to avoid these situations.

- Data Corruption due to Out-Of-Synch Medium: The cache might receive updates that are not yet persisted on the external medium, as explicitly allowed by DES 052. A problem might arise due to changes by other processes or threads. These cannot be handeled in a general way by `jMeta`. Thus we have introduced the locking of media in DES 052. Even this cannot give a full protection for some OSs. The user is in any case informed about irresolvabe inconsistencies by a runtime exception.

Finally, we want to list a design decision rejected during a proof of concept, which was to provide a mechanism of skipping bytes for `InputStream`s instead of reading them into the cache, here is why:

DES 053: **The `Media` API does not provide the option to skip bytes of an `InputStream` instead of reading them into the cache**
It sounds like a good idea to offer the configurable possibility to skip bytes from an `InputStream` instead of unnecessarily reading them (and put them into a cache). This mainly applies for the case when you are currently at offset x, but now you want to read bytes from the stream starting at offset $x + 100$. You might never want to access the bytes between x and $x + 100$. So it would be worthwile to allow the possibility to simply skip them instead of reading them into memory and into the cache.
However, `InputStream.skip` is not as straightforward as one could wish. It does not guarantee to skip the number of bytes given, but it might skip fewer bytes or even return a negative number. It might also throw an `IOException`, which might or might not include the case of reaching the end of medium. Although not specified, there might be the same behavior as for read, that `InputStream.skip` might block. Furthermore the javadocs specify that it is only supported for streams that support seeking. All in all, this gives the impression that the method is highly platform and implementation-dependent. How to bring this implementation into a reliable form that guarantees to always skip the given number of bytes or block (possibly with timeout)?

Begründung: It is too complex to implement the method reliably, thus we omit it and only offer the possibility to read ahead until a given offset. All bytes read are possibly read into the cache. However, the cache is "self-cleaning" according to DES 053, if a maximum size is configured. This mechanism should be sufficient for achieving a moderate heap usage.

Nachteile: Probably more heap usage and bytes might be unnecessary read and kept in memory.

Implementing the discussed caching mechanisms is a big challenge. It will be detailed more in the implementation part of this component. Here, we can only exclude one way of implementing it:

DES 054: `MappedByteBuffer` **will not be used to implement caching**
You could come with the idea to use the Java NIO class `MappedByteBuffer` for implementing the caching of DES 054. However, we do not use it and implement another solution "by hand".

Begründung: It is not guaranteed, that each OS supporting Java also supports a `MappedByteBuffer`. It is also not guaranteed that the data "cached" is really present in RAM and thus accessible faster. Furthermore, it is indicated that for each concecutive region of a medium a new `MappedByteBuffer` instance including new OS call would need to be created. Thus this approach is unpredictable and might lack the desired benefits.

Nachteile: The "by hand" caching is harder to implement.

At the end we shortly list a special case of caching for byte array media:

DES 055: For byte array media, caching is always disabled
For byte array media, caching is always disabled

Begründung: byte arrays already are in RAM, caching would just be unncessary overhead

Nachteile: No disadvantages known

Reading Access to the Medium

The two-stage write protocol introduced in "11.1.1 Two-Stage Write Protocol" brings up some questions regarding reading the data. The most important among these: What does the user need to consider after calling a writing operation (stage 1) and before *flush*ing these changes (stage 2)? Especially: What do reading calls return after already having made changes, that are however not yet *flush*ed? The possibilities we have:

1. Either the last persisted state on the medium after opening it or the last successful *flush*, respectively,

2. Or already a state the includes any "pending" changes introduced by writing calls before the *flush*?

You could base your answer on the following: For sure alternative (2), as it is this way that e.g. transactions mostly work for code accessing databases. What you have already written during the transaction, you re-read later, too, even if the transaction is not yet persisted. However, the view of `jMeta` is different:

DES 056: **The user can only read what is currently persisted on the medium**

Even if there are pending changes not yet *flush*ed (e.g. inserts, removes), with `Media` the user can only see the latest flushed state.

Begründung: The changes the user has registered are coming form the user, and he thus could potentially keep bookmarks of them. Therefore their sole management by `Media` is - at this point in time - not strictly necessary. Furthermore it must still be possible to read the data of a datablock that is threatened by a pending remove.
Another good reason for this behaviour is that the reading operations are much less complex, as they do not need to consider any pending changes. The code that reads data can be sure to always only work on a persistent (or at least a cached) state. Thus it cannot occur that logic is basing on data that is not yet persisted.

Nachteile: The expectation that "what I have written before - even if pending - I can re-read afterwards" is not fulfilled. The user must manage this for changed data by himself, at least temporarily until the next flush.

In "11.1.1 Caching", caching has been discussed in detail. For buffering, we first need an operation to do buffering without actually returning the buffered data:

DES 057: **Explicit operation for buffering of media data**

There is an operation *cache* which buffers n data bytes starting at a given offset, without returning this data. Additionally, there is an operation to query the number of bytes buffered concecutively starting at a given offset. Of course, this might lead to an "end of medium" situation indicated by the method to the caller.

Begründung: Necessary for implementing DES 057. Of course one could ask: Why isn't it sufficient to just provide a single `getData` operation that returns data, either from the cache or from the medium. If the data was not yet in cache, it also adds it to the cache. The reason is: The code might not want the bytes yet! It just wants to give a statement like "At this point in time, I know how much bytes I might need to read later, so please already buffer them. But do not give the bytes to me, because at this point in the code I cannot really use them and it would complicate my code strucutre." For instance, if only providing one method returning the data, the code must pass the read data as parameter to other methods to read it. Instead of doing this, the code can just buffer the needed number of bytes, then call other code to get just the data it needs without needing to fiddle keeping track of the last read byte.

Nachteile: No disadvantages known

Additionally, you must be able to get your hands at the buffered data:

DES 058: Explicit operation to get medium bytes
There is an operation *getData* which returns *n* data bytes starting at a given
offset.

Begründung: Without it there would not be any possibility to read data from
a medium, as *cache* only buffers it internally without returning it.

Nachteile: No disadvantages known

Now the question arises, how the operation *getData* interacts with the cache,
which is answered here:

**DES 059: *getData* combines data from the cache with data form the
medium and updates the cache thereby, if necessary**
getData reads data from the cache, if the given range is entirely contained in it.
Is it not entirely contained in the cache, *getData* reads the bytes present in the
cache, and reads the non-present ones from the medium, adding it to the cache
afterwards. Thus data is combined from the two sources.

Begründung: To ensure efficient reading, *getData* can be used as such to fetch
data from the cache, if anyhow possible. Only if there is at leaast one byte not
in the cache, the medium must be accessed directly. Updating the cache by read
data is useful, to ensure later calls to query the same data can fully leverage the
cache and do not need another access to the external medium.

Nachteile: No disadvantages known

Should we provide a way to force medium access when getting data?

**DES 060: *getData* provides no specific mode or configuration to
ignore the cache and always read from the medium**
getData does not provide a forced read mechanism, but it always only reads
data from the external medium that it cannot find in the cache.

Begründung: It is not clear when using code should use the forced or the
unforced mode. If the using code somehow can magically see that the underlying
medium was changed by other processes, it could do a forced direct read. But in
this case, everything is lost already, because you can never know what the other
process did. A better way to ensure integrity and consistency would be for the
using code to close the medium and reopen another access instance.

Nachteile: No disadvantages known

We want to define now how the read media data is represented:

DES 061: Read media data is represented as read-only `ByteBuffer`
Read data is not returned in the form of `byte` arrays, but as `ByteBuffer`
instances that are read-only.

Begründung: Firstly, users can directly gain profit from conversion functions
offered by `ByteBuffer`, on the other hand the implementation is more flexible
when it comes to the content of the `ByteBuffer`, as only the bytes between
`position()` and `limit()` can be read. Using this e.g. an internally managed,
much bigger `ByteBuffer` object can be returned as a read-only view instead of
copying it.

Nachteile: No disadvantages known

For efficiency reasons, we define the following:

**DES 062: Handle reading from a single already cached region or a
size smaller than the maximum read-write block size as special case**
If a read offset and size for *getData* is exactly hitting a single cache region, and
this single region fully contains the range to read, the `ByteBuffer` corresponding
to this region with adapted position and limit is returned instead of allocating a
new `ByteBuffer` and copying bytes, which will happen in any other case.
Similarly, if a range is not cached and needs to be read, and if the range's size is
below the maximum read-write block size, again no copying happens, but the
read `ByteBuffer` is directly returned.

Begründung: The case of an already cached region fully covering the range to
read can be considered as at least the use case covering 80% of the typical uses.
The reason is: Usually, the users should use cached media. And usually, they
should call *cache* before *getData*, covering e.g. a whole header. Thus, reading
individual fields later with `getData` will always hit the cache. Thus, for this 80%
case, we could optimize the library performance a lot by simply not copying.

Nachteile: Slightly more complexity and testing effort involved

---

Let's discuss the topic of timeouts. In Java, each reading and writing I/O call
might block. How to deal with this? The following design decision clearly states
it.

> **DES 063:** **jMeta does not support any timeouts, neither reading nor writing**
>
> `Media` does not offer the possibility to configure timeouts for any reading or writing actions, and likewise, it does not implement any measures to prevent these actions from blocking arbitrarily long
>
> **Begründung:** Both for file or stream access, read and write operations, including determining where we are or truncation might or might not block. This is - unfortunately - OS and implementation dependent and cannot be predicted. It is possible and was tried to implement a parallel thread to execute the action against the medium and the main thread to monitor the time taken by the other thread and retrieve the result after a given timeout. While this is easily possible using Java's `Future`s, it is not so easy to really terminate the blocking action and its thread. In reality, on some OSs the action is really interruptible, on others it is not. This might also depend on the implementation. Thus, `jMeta` won't implement anything that would try to convince the user it can actually do it, leading also to increased complexity. Instead, the user must use his own mechanisms, i.e. an own custom `InputStream` implementation, using multithreading and monitoring of calls from the outside, or using implementation-specific timeouts such as for `SocketInputStream`. Furthermore, it is also problematic what state the medium is in after the timeout was detected. What shall the library or the user do with this implementation? Retry, fail, close and retry? There is not always an easy answer to it.
>
> **Nachteile:** Users might need to write more custom code themselves, if they strictly require this for mediums they use.

11.1.2. API Design

On the basis of the design decisions made in the previous section, we can now develop an API design for the component `Media`. The API is the public interface of the component, i.e. all classes that can be used by other components to access the `Media` functionality.

Reprasentation of a Medium

The medium has appeared a lot of times already as a term, thus a representation as a class makes sense.

DES 064: **Media are represented as interface and implementation class with following properties**
A medium is represented as Java interface `Medium` and allows users of jMeta to specify a concrete physical medium (i.e. the implementations of the interface `Medium`). As implementations we support a `FileMedium` according to DES 064, according to DES 064 aan `InputStreamMedium` and according to DES 064 a `InMemoryMedium`.
A medium has the following properties:

- Is random-access: Yes/No - **Motivation:** This property has strong impact on the read and write process, yet it is an intrinsic property of the MEDIUM itself and not of the access mechanism. Thus it is directly available for at a MEDIUM.

- Read-only: Yes/No - **Motivation:** This property disables writing in practice if set to "Yes". Some MEDIA can never be written (e.g. `InputStream`s), for others it is possible. This flag shall be used to also give the `jMeta` user a possibility to signal he wants to only access read-only.

- Current lenght in bytes (only relevant for random-access) - **Motivation:** Java offers queries for each kind of `Medium` except `InputStream`. Thus this should be implemented directly in the `Medium` implementation. For `InputStream` and non-random-access media in general, terms like length to not make much sense. Thus here there is no value, but a constant indicating an unknown length. In spirit pf design decision DES 064, it is a currently persisted lenght and not a length including any not-yet persisted changes.

- A clear text name of the MEDIUM - **Motivation:** This is helpful for identification purposes of the `Medium` e.g. in log output. It can be derived from e.g. a file name, depending on the medium type.

- The "wrapped" object representing the raw medium or its access mechanism, e.g. the file, the `InputStream` or the byte array.

Begründung: It can be controlled in detail which medium types are supported. The user can specify the medium to use in a comfortable way. Further API parts get more easier, as their interfaces must not distinguish between different media types, but rather only use the abstaction that `Medium` offers. Motivation for each of the properties see the listing above.

Nachteile: No disadvantages known

Due to consistency reasons there are some restrictions regarding the manipulation of media properties:

> **DES 065:** **If a `Medium` implementation is writable, it must also be random-access**
> Every in principle writable `Medium` implementation must be random-access, too.
>
> **Begründung:** The `jMeta` APIs for writing content can thus concentrate on random-access output media. No separate API design and implementation for output media that are not random-access is necessary. The API gets easier for end-users. Lack of non-random-access output media such as `OutputStream`s can be mitigated via the examples in DES 065.
>
> **Nachteile:** No disadvantages known

Here is a very importante note for byte array media:

> **DES 066:** **For byte array media, a writing method for resetting the whole byte array is necessary**
> The user can reset the bytes of the medium via a public method `setBytes` of class `InMemoryMedium`.
>
> **Begründung:** It is mostly not harmful to offer the method as public, it is even an advantage for the users, as he can set the bytes himself. Only between registering write operations and a flush, this call leads to unexpected behaviour. This methode is very important for the implementation: Via writing actions, the byte array must be extended or shrinked in some situations. This basically means reacreating and copying the array. The method must thus be public, as the corresponding implementation funcitonality will be for sure placed in another package.
>
> **Nachteile:** No disadvantages known

Positions in and Lengths of a Medium

In each case where dare is read from or written to a MEDIUM, the question "where?" arises. Usually libraries use integer or long variables to represent offsets. It must be said however: Offsets do not only make sense for random-access media. You could also interpret them as offset since start of reading from an `InputStream`, which is actually the way it is done in `jMeta`. We decide:

DES 067: **Byte offsets are used for any kind of MEDIA**
Byte offsets that refer to a position on a MEDIUM are used for all media types:
random-access and non-random-access. For byte streams they refer to the
position of the current byte since start of reading the first byte after opening the
stream, which has offset 0. The offset-based reading is simulated as specified in
DES 067 and DES 067, because when directly reading from an `InputStream` via
Java API, offsets are not needed, it is always read from the current position of
the stream.

Begründung: We must therefore distinguish between random-access and
non-random-access only at a few places in the implementation. Users can use
the API uniformly and irrespective of the actual medium type (with restrictions:
see DES 067).

Nachteile: No disadvantages known

It makes not so much sense to represent offsets only via a primitve data type.
Instead, the representation as a user-defined data type offers some advantages:

DES 068: **`jMeta` uses the interface `MediumOffset` to represent offsets on
a MEDIUM.**
The interface binds both the MEDIUM and the offset on this MEDIUM together,
and thus is a kind of "global" address of a byte. Next to reading medium and of
offset, it offers some helper methods:

- `behindOrEqual`: Returns true if another `MediumOffset` is located on the
  same medium behind of at the same position as this instance.

- `before`: Returns true if another `MediumOffset` is located on the same
  medium before the position of this instance.

- `advance`: Creates a new `MediumOffset` that is located by the given byte
  number before (negative argument) or after (positive argument) this
  instance.

Begründung: We clearly state how the library deals with offsets. We can thus
implement some helper functions into the datatype (e.g. validation, offset
comparison, advance etc.) which ensure reuse and ease working with offsets in
general.

Nachteile: No disadvantages known

Now we come to a central decision when it comes to dealing with lengths and
offsets:

DES 069: `jMeta` **uses long for length and offset specifications, byte is always its unit**

In `jMeta`, lenghts and offsets are always specified using the Java datatyp long. The lenght is in any case the number of bytes, offsets are zero-based, linearly increasing byte offsets.

Begründung: This guarantees uniformity. However, we also want to meet the requirement "**?? ??**". Integer with a maximum of 4.3 GB is already too limited, which leaves only long as a viable option. The datatype long allows for positive numbers up to $2^{63} - 1 = 9223372036854775807$, i.e. approximately $9 \cdot 10^{18}$ bytes, which is 9 exabytes or 9 billion gigabytes. From current point of view, such lenghts and offsets for input media, even for streams, should be sufficient for some decades to come. Furthermore, big data chunks are almost in any case subdivided in small units that can be easier handled, and these small units will not have big lengths. Even the Java file I/O uses long as offset and length datatype in most cases.

Nachteile: More memory for saving offsets and lengths is necessary. If we look at the development of storage media, storage needs and processing speed it might be that in 100 years the maximum data volume of long will be reached. If `jMeta` is still used in these future scenarios, a change request would be worth it!

A rather seldom special case is dealt with in the following design decision:

DES 070: **No special handling of long overflows**

For unusal long uninterrupted reading from `InputStream` you could think that even when using long, it could come to an overflow in some time. This is however very unlikely, thus this case is not treated. The implementation always assumes taht the current offset is positive and can be incremented without reaching the max long number.

Begründung: Even here it holds true: The datatype long allows positive numbers up to $2^{63} - 1 = 9223372036854775807$. Let us assume that an implementation could make it to process 10 GB per second, then it would still need 9 billion seconds, i.e. nearly 30 years, to reach the offset limit and create an overflow.

Nachteile: No disadvantages knownn

Now the problem arises that the medium changes due to writing access. How do the offsets change in this case? Is it necessary to update already created `Medium-Offset` instances according to the changes on the mediums, or not? If yes, when this needs to happen? In principle, we could see following alternatives:

1. Never update already created `MediumOffset` instances

2. Update already created `MediumOffset` instances directly for each pending

change registered (see DES 070)

3. Update already created `MediumOffset` instances only when an explicit *flush* according to DES 070 occurs

Assume that `MediumOffset` instances are not updated when writing. That means the user code remembers a position of an element in form of a `Medium-Offset` instance, and uses it to read or write data. If e.g. an inseration operation takes place on the medium before the offset of the `MediumOffset` instance, then the instance refers to another data byte than before, and thus not anymore to the object it was referring to initially. We should not only think of raw bytes but - as necessary for data formats - *objects*, i.e. parts of the binary data that form a specific unit with which has a specific meaning, representing something. Then failure to update the offset is fatal. Code using `Media` locates an object at the wrong place if the medium changed before that offset meanwhile.

To formulate the following design decision a bit easier, the vague term of "Object" used above is now defined a bit sharper: An object is a consecutive byte unit starting at aspecific offset x and it has a length of n bytes. `remove`, `insert` and `replace` in the offset interval $[x, x + n]$ change these objects, which cannot be in any case specifically treated by `Media`.

DES 071: `Media` **needs to automatically update** `MediumOffset` **instances after medium changes:** `remove` **and** `insert`

All `MediumOffset` instances ever created for a medium must be updated automatically whenever this medium changes. The kind of update needed is more complex than you would think on first glance.

Let x be the start offset of a collection of n bytes (an "object"), let y be the insert or remove offset and k the number of bytes to insert or remove. Let $\overline{x}$ be the offset of the `MediumOffset` instance after updating. Then the following detailed rules apply:

- `insert` *before the object start offset* x: Is $y \leq x$, then $\overline{x} := x + k$, including the case $y = x$.

- `insert` *behind the object start offset* x: Is $y > x$, then $\overline{x} := x$, i.e. such insertions of course do not change the offset of byte x. Insertions might happen before $x + n$, essentially splitting the object.

- `remove` *before the object start offset* x *without overlap:* Is $y + k \leq x$, then $\overline{x} := x - k$. Thus k bytes are removed before the object, however the removed region does not overlap with the object.

- `remove` *before the object start offset* x *with overlap:* Is $y \leq x$, but $y + k > x$, then the removed region overlaps the object. It is thus a *truncation* of the object starting at front, and it might even reduce the object to length 0. Thus the start offset of the object shifts $x - y$ to be equal to y, i.e. $\overline{x} := y$.

- `remove` *behind the object start offset* x: Is $y > x$, then $\overline{x} := x$, i.e. the object start offset remains unchanged, of course also in the case that $y < x + n$. In the latter case, however, the object is truncated at its end.

Begründung: `MediumOffset`s are both handed out to the user as well as used to manage cache objects. If changes to the medium happens, all `MediumOffset`s that are already in user hands or are internally used to manage data are rendered invalid. Thus, we would need to write code to detect such `MediumOffset`s as invalid whenever used, or to invalidate the current cache content. Instead of doing so, we simply update all `MediumOffset`s previously created according to the kind of change, thus practically still letting them point to the same "object" as before (despite removing the medium bytes as special case). The `MediumOffset`s can thus be used further on.

Nachteile: A central management of `MediumOffset` instances must be implemented (see DES 071).

`replace`s are discussed in the next design decision:

DES 072: `Media` **needs to automatically update** `MediumOffset` **instances after medium changes:** `replace`
For `replace`, the update of already created `MediumOffset`s is similar, but any offsets within the replaced region remain unchanged. In detail: Let x be the start offset of a collection of n bytes (an "object"):

- `replace` *behind the object start offset x:* The same as insert and remove behind the start offset, i.e. does not change it but might truncate or split an existing object starting earlier.

- `replace` *before the object start offset x without overlap:* For an inserting replace, The same as for `insert` before x. For a removing replace, the same as for `remove` before x without overlap. For an overwriting replace, no changes are applied to x.

- `replace` *before the object start offset x with overlap:* The replaced region overlaps with an existing object. Here, x remains unchanged by the replacement.

Begründung: There is no surprose for replaces behind the object start offset and those before the start offset without overlap. The only question is: If there is an overlap, i.e. x lies within the replaced region of bytes, why do we not update it? The reason is: Because of the replacement by other bytes, the object is anyway changed, the correct semantics seems to be to let the `MediumOffset`s point to x still point to x.

Nachteile: A central management of `MediumOffset` instances must be implemented (see DES 072).

As already indicated by DES 072 the automatic updating of already created `MediumOffset` instances requires that only `Media` may create `MediumOffset` instances. These must be managed in a kind of pool to be able to automatically update them in case of writing operations.

DES 073: `MediumOffset` **instances are centrally managed by** `Media` **and cannot be directly created by users of the component**
The lifecycle of `MediumOffset` instances is controlled by `Media`. They are created and returned to the user via a factory method.

Begründung: It is strictly required to implement DES 073. Instances that have been created by the user cannot be update automatically, thus we have to ensure the manual creation by the user does not happen.

Nachteile: More complex instantiation of `MediumOffset` instances.

The question *when* to update `MediumOffset` instances has still not been answered yet. The following design decision clearly defines this:

DES 074: `MediumOffset` **instances are only updated after a *flush***
According to DES 074 `MediumOffset` instances are automatically updated in case of medium changes. This automatic update only happens at *flush* time.

Begründung: Assumed that `MediumOffset` instances would already be updated whenever a pending change is registered using *insert*, *replace* or *remove*. In this case the following would be necessary:

- When reading data, this data is not necessarily in a cache. This indicates that reading from external medium is necessary. If all `MediumOffset` instances would reflect a state including any pending changes, they would no longer correspond to the state of the external medium. If you would now want to read or write to the external medium, the real offset on the external medium would need to be "reconstructed" based on the changes made so far, everytime you want to know where current data resides on the medium. This implies a complex coding overhead that would not ease debugging errors or understanding the current state of instances.

- The operation `undo` according to DES 074 requires that offsets would need to be "re-adapted" if a pending changes is undone again. Again this is additional complexity.

If `MediumOffset` instances in contrast are first updated after a *flush*, then no reconstruction of original offsets based on already made changes is necessary.

Nachteile: No disadvantages known

This directly implies the following design decision:

DES 075: **In** `Media`**, offset specifications always are offsets on the external medium as it was looking like after the last *flush* or after opening it initially**
For operations of `Media` that take an offset as argument, this offset refers to a location on the external MEDIUM after the last *flush* or the initial opening - in case no *flush* has occurred yet. These offsets must especially be located within the interval $[0, \text{length}]$, where "length" is the current length of the medium in bytes.

Begründung: Naturally follows from DES 075. For users, the offset situation remains stable and logical, he does not need to maintain a history of *insert*, *replace* and *remove* operations. Likewise, the offsets stay stable for the implementation, too: Checking offsets and organisation of internal data structures can be based on this invariant.

Nachteile: No disadvantages known

Semantics of Writing Operations

In DES 075, we have defined the primitive writing operations *insert*, *replace* and *remove* that are essential for `Media`. In the same section, we have listed basic requirements for writing that lead to these operations. The API of `Media` includes their guaranteed behavior. It is very important to define interrelations between these operations, especially how they behave for overlapping offset areas of the medium. These things are defined by the following design decisions. The behaviors are part of the API contract and must be documented as such for the API users.

We start with how multiple *insert* operations behave:

DES 076: *insert* concatenates insertions in call order

1. Step 1: *insert* at offset x, Step 2: *insert* at different offset: Both calls are allowed, they do not influence each other.

2. Step 1: *insert*, Step 2: *insert* at the same offset: *insert* concats, each call with the same offset determines a new, consecutive insertion, i.e. insertions at the same medium location are done with increasing offsets. Let "Call 1" be the earlier call with insertion length n_1, "Call 2" the later call at x with insertion length n_2. The end result on the medium after *flush* is:

   - At offset x, the insertion data of "Call 1" is located
   - At offset $x + n_2$, the insertion data of "Call 2" is located.

Begründung:

1. See requirement `AMed01`

2. See requirement `AMed08`

You could alternatively interpret "insert" as such that the second call inserts data *before* the previous earlier one. However, the design decision says that "insert" inserts before the currently persisted medium byte at the insertion offset. Concatenating allows user code to linearly insert stuff with increasing offsets, which is in most cases the convenient and expected behavior.

Nachteile: The second possible interpretation sketched above might lead to surprises in a few use scenarios.

Before looking at the interactions between *insert*s, *remove*s and *replace*s in detail, we have to deeper think about `AMed09`. The requirement is to allow *insert*s and one of these other operations at the same offset in arbitrary order. What is the meaning behind? This is clarified by the following design decision:

> **DES 077: *insert* at the same offset as *remove* and *replace* means to insert before remove and replace, irrespective of schedule order**
> No matter if you first call *insert* at offset x, then *remove* or *replace* at offset x, or the other way round: The meaning is that you want to insert new bytes before the bytes to remove or replace.
>
> **Begründung:** If you want to insert something behind the replacement or removed region, the insertion offset must point to the offset of the first byte behind the replacement or removed region. Thus, calling *insert* after *remove* or *replace* cannot have the meaning "first execute the replace or remove, then insert the bytes behind the removed or replaced region". Thus, we have to ignore the sequence and ensure *insert*s at the same offsets as *remove* or *replace* are always executed first.
>
> **Nachteile:** No disadvantages known

We now look at how *insert* and *remove* interact with each other:

DES 078: *insert* is revoked by overlapping *remove*s, *insert*s within already removed regions are not allowed
The following cases can be identified:

1. Step 1: *insert* at offset x, Step 2: *remove* n bytes at offset y, where x is not located within the removed range $[y, y + n)$: Both calls are allowed, they do not influence each other.

2. Step 1: *remove* n bytes at offset y, Step 2: *insert* at offset x, where x is not located within the removed range $[y, y + n)$: Both calls are allowed, they do not influence each other.

3. Step 1: *insert* at offset x, Step 2: *remove* at same offset: Both calls are allowed, with the meaning to first insert new bytes at offset x, then removing existing bytes starting at offset x (see DES 078).

4. Step 1: *remove* at offset x, Step 2: *insert* at same offset: Both calls are allowed, with the meaning to first insert new bytes at offset x, then removing existing bytes starting at offset x (see DES 078).

5. Step 1: *insert* at offset x, Step 2: *remove* n bytes at offset y, where x is contained in the removed range $[y, y + n)$: The insert is revoked by the remove, i.e. will not be executed during a *flush*.

6. Step 1: *remove* n bytes at offset y, Step 2: *insert* at offset x, where x is contained in the removed range $[y, y + n)$: The second call is rejected with an exception, as it is pointing into an already removed region.

Begründung:

1. See requirement `AMed01` and `AMed02`

2. See requirement `AMed01` and `AMed02`

3. See requirement `AMed09`

4. See requirement `AMed09`

5. See requirement `AMed10`

6. See requirement `AMed13`

Nachteile: Then, how to implement write requirement `AMed04`? See DES 078.

Now we are left with clarifying how *insert* and *replace* interact with each other. This is essentially the same as between *insert* and *remove*:

DES 079: *insert* is revoked by overlapping *replace*s, *insert*s within already replaced regions are not allowed

The following cases can be identified:

1. Step 1: *insert* at offset x, Step 2: *replace* n bytes by m new bytes at offset y, where x is not located within the replaced range $[y, y+n)$: Both calls are allowed, they do not influence each other.

2. Step 1: *replace* n bytes by m new bytes at offset y, Step 2: *insert* at offset x, where x is not located within the replaced range $[y, y+n)$: Both calls are allowed, they do not influence each other.

3. Step 1: *insert* at offset x, Step 2: *replace* at same offset: Both calls are allowed, with the meaning to first insert new bytes at offset x, then replacing existing bytes starting at offset x (see DES 079).

4. Step 1: *replace* at offset x, Step 2: *insert* at same offset: Both calls are allowed, with the meaning to first insert new bytes at offset x, then replacing existing bytes starting at offset x (see DES 079).

5. Step 1: *insert* at offset x, Step 2: *replace* n bytes by m new bytes at offset y, where x is contained in the replaced range $[y, y+n)$: The insert is revoked by the replace, i.e. will not be executed during a *flush*.

6. Step 1: *replace* n bytes by m new bytes at offset y, Step 2: *insert* at offset x, where x is contained in the replaced range $[y, y+n)$: The second call is rejected with an exception, as it is pointing into an already replaced region.

Begründung:

1. See requirement `AMed01` and `AMed03`

2. See requirement `AMed01` and `AMed03`

3. See requirement `AMed09`

4. See requirement `AMed09`

5. See requirement `AMed11`

6. See requirement `AMed13`

Nachteile: Then, how to implement write requirement `AMed05`? See DES 079.

Saying all this, it is not possible to implement `AMed04` ("it is possible to change or remove parts of an already done insertion before a flush") and `AMed05` ("it is possible to change or remove parts of an already done replacement before a flush") by using subsequent inserts, removes and replaces to modify an already inserted or replaced block of data before a flush. This is of cause already clear when looking at DES 079: Offets of these operations always only refer to currently persisted

data, so you e.g. cannot change a prior insert not yet flushed with a remove. Then how are these requirements met? Here is how it could be done:

DES 080: **Meeting requirements `AMed04` and `AMed05` is done outside of `Media`, yet using its *undo* feature**

`AMed04` and `AMed05` can only be met outside `Media`. Using code must detect that a parent of the changed field was already scheduled for insertion or replacement. If that is the case, they have to "re-compute" the overall insertion or replacment bytes, undo the previous insertion or replacement using `Media` and finally schedule a new insertion or replacement containing the changed bytes. Alternatively, the implementation using `Media` might freeze a data block for change once its scheduled for insertion or replacement and throws an exception if someone tries to modify it afterwards. The details of this are defined in the design of `DataBlocks`.

Begründung: `Media` could somehow support here by offering modification functions for already done *insert*s or *replace*s. However, this would also at least require the using code to detect the change in a parent, and also recompute. It would make the API more complex. Using *undo*, the using code has just slightly more work to do.

Nachteile: No disadvantages known

We already clarified how insert interacts with insert, remove and replace, in any order. We are now only left to clarify how multiple removes and replaces interact with each other. Multiple *remove*s interact with each other as follows:

> **DES 081: *remove* allows no overlaps by other *remove*s, only later calls with bigger region make earlier calls obsolete**
> The following cases can be identified:
>
> 1. Step 1: *remove* n bytes at offset x, Step 2: *remove* m bytes at offset y without any overlaps to $[x, x+n)$: Both calls are allowed, they do not influence each other.
>
> 2. Step 1: *remove* n bytes at offset x, Step 2: *remove* $m \geq n$ bytes at offset $y \leq x$ with $[x, x+n) \subseteq [y, y+m)$: The second call to *remove* fully encloses the removed range of the previous *remove* call, so the previous call is revoked, i.e. it will not be executed during a *flush*.
>
> 3. Step 1: *remove* n bytes at offset x, Step 2: *remove* m bytes at offset y with $[y, y+m) \subseteq [x, x+m)$: The second region to be removed is fully contained in the region already removed by the previous call. The second call is rejected with an exception.
>
> 4. Step 1: *remove* n bytes at offset x, Step 2: *remove* m bytes at offset $y \in (x, x+n)$ with $y + m > x + n$: The second call is an overlapping call, that removes additional bytes behind the first remove call, but still includes some bytes of the region removed with the first call. The second call is rejected with an exception.
>
> 5. Step 1: *remove* n bytes at offset x, Step 2: *remove* m bytes at offset $y < x$ with $y > x, y + m < x + n$: The second call is an overlapping call, that removes additional bytes before the first remove call, but still includes some bytes of the region removed with the first call. The second call is rejected with an exception.
>
> **Begründung:**
>
> 1. See requirement `AMed02`
>
> 2. See requirement `AMed10`
>
> 3. See requirement `AMed13`
>
> 4. See requirement `AMed12`
>
> 5. See requirement `AMed12`
>
> **Nachteile:** No disadvantages known

Interactions between *remove* and *replace* are identical to this, as defined in the following design decision:

***DES 082: *remove* allows no overlaps by *replace*s, only later calls with
bigger region make earlier calls obsolete***
The following cases can be identified:

1. Step 1: *remove* n bytes at offset x, Step 2: *replace* m bytes by r new bytes
   at offset y without any overlaps to $[x, x+n)$: Both calls are allowed, they
   do not influence each other.

2. Previous case, exchange order of *remove* and *replace*: Same result

3. Step 1: *remove* n bytes at offset x, Step 2: *replace* $m \geq n$ bytes by r new
   bytes at offset $y \leq x$ with $[x, x+n) \subseteq [y, y+m)$: The replaced region of
   replace fully encloses the removed range of the previous *remove* call, so the
   previous call is revoked, i.e. it will not be executed during a *flush*.

4. Previous case, exchange order of *remove* and *replace*: Same result

5. Step 1: *remove* n bytes at offset x, Step 2: *replace* m bytes by r new bytes
   at offset y with $[y, y+m) \subseteq [x, x+m)$: The second region to be replaced
   is fully contained in the region already removed by the previous call. The
   second call is rejected with an exception.

6. Previous case, exchange order of *remove* and *replace*: Same result

7. Step 1: *remove* n bytes at offset x, Step 2: *replace* m bytes by r new bytes
   at offset $y \in (x, x+n)$ with $y+m > x+n$: The second call is an
   overlapping call, that replaces additional bytes behind the first remove
   call, but still includes some bytes of the region removed with the first call.
   The second call is rejected with an exception.

8. Previous case, exchange order of *remove* and *replace*: Same result

9. Step 1: *remove* n bytes at offset x, Step 2: *replace* m bytes by r new bytes
   at offset $y < x$ with $y > x, y+m < x+n$: The second call is an
   overlapping call, that replaces additional bytes before the first remove call,
   but still includes some bytes of the region removed with the first call. The
   second call is rejected with an exception.

10. Previous case, exchange order of *remove* and *replace*: Same result

Begründung: For (1.) and (2.): See requirement `AMed02` and `AMed03`. For (3.):
See requirement `AMed11`; For (4.): See requirement `AMed10`. For (5.) and (6.):
See requirement `AMed13`. For (7.) to (10.): See requirement `AMed12`.

Nachteile: No disadvantages known

Now we are just left to clarify how multiple *replace* operations interact with
each other:

DES 083: *replace* **allows no overlaps by other** *replace***s, only later calls with bigger region make earlier calls obsolete**
The following cases can be identified:

1. Step 1: *replace* n bytes by r_1 new bytes at offset x, Step 2: *replace* m bytes by r_2 new bytes at offset y without any overlaps to $[x, x + n)$: Both calls are allowed, they do not influence each other.

2. Step 1: *replace* n bytes by r_1 new bytes at offset x, Step 2: *replace* $m \geq n$ bytes by r_2 new bytes at offset $y \leq x$ with $[x, x + n) \subseteq [y, y + m)$: The second call to *replace* fully encloses the replaced range of the previous *replace* call, so the previous call is revoked, i.e. it will not be executed during a *flush*.

3. Step 1: *replace* n bytes by r_1 new bytes at offset x, Step 2: *replace* m bytes by r_2 new bytes at offset y with $[y, y + m) \subseteq [x, x + m)$: The second region to be replaced is fully contained in the region already replaced by the previous call. The second call is rejected with an exception.

4. Step 1: *replace* n bytes by r_1 new bytes at offset x, Step 2: *replace* m bytes by r_2 new bytes at offset $y \in (x, x + n)$ with $y + m > x + n$: The second call is an overlapping call, that replaces additional bytes behind the first replace call, but still includes some bytes of the region replaced with the first call. The second call is rejected with an exception.

5. Step 1: *replace* n bytes by r_1 new bytes at offset x, Step 2: *replace* m bytes by r_2 new bytes at offset $y < x$ with $y > x, y + m < x + n$: The second call is an overlapping call, that replaces additional bytes before the first replace call, but still includes some bytes of the region replaced with the first call. The second call is rejected with an exception.

Begründung:

1. See requirement `AMed02`

2. See requirement `AMed11`

3. See requirement `AMed13`

4. See requirement `AMed12`

5. See requirement `AMed12`

Nachteile: No disadvantages known

Another problem: How to map the actual data to a data block before a *flush*? The offset alone is not unique anymore in the face of multiple *insert*s at the same offset before their *flush*. If you now want to relate an action (*insert, remove, replace*) data to its (current or future) offset, the offset alone is not sufficient to

state clearly which action happened first at the offset.

An answer is given in the following design decision that explains how action, data and offset are brought into close relation:

DES 084: **Each of the writing operations returns an instance of a class** MediumAction **to describe the action in more detail**
This class contains following data:

- The kind of action (*insert*, *replace*, *remove*); **Motivation:** The user must be able to know the kind of change

- MediumOffset of the action; **Motivation:** It must be clear where the change happened or must happen

- Data of the action (length or bytes to write); **Motivation:** It must be clear what needs to be changed.

- Number of actually affected medium bytes (0 for *insert*, number of bytes to remove for *remove*, number of bytes to replace for *replace*; **Motivation:** For replace only one length is not enough as the number of bytes to replace may be different from the length of the replacement bytes.

- Validity: Handle is already persisted by a *flush* or still pending; **Motivation:** Thus it can be clearly state from outside whether the data must still be persisted and thus must be taken from the instance of the user requires to read them, or the data has already been written to the external medium.

Begründung: According to DES 084, the user can only read data that is currently persisted.
Nevertheless it is necessary that application code can also re-read data previously registered for writing, but not yet persisted by a *flush*. That now becomes possible with the MediumAction class that is returned by *insert*, *replace* and *remove*. Is the MediumAction still pending, the application code can return the pending bytes from the MediumAction, otherwise by directly accessing the Media read functionality to fetch the currently persisted bytes.
Instances of MediumAction can ideally be used for internal data management by Media.

Nachteile: No disadvantages known

End medium access

We still need an operation to end the medium access, thus we define:

> **DES 085: Operation *close* ends the medium access and empties the cache, consecutive operations are not possible on the medium**
> A user can manually end medium access by calling *close*. It is then no longer possible to access the medium via the closed access way. The user must explicitly reopen the medium to access it again.
>
> **Begründung:** The implementation works with OS resources such as files that must be closed. Furthermore cache content and other memory is not freed anytime if you could not close the medium.
> Closing cannot be implemented automatically but must be explicity called by the user.
>
> **Nachteile:** No disadvantages known

The public API of medium access

Based on the previous design decisions we now design the public API of the component `Media`. Until now, we only introduced the classes `MediumOffset`, `Medium` and `MediumAction` as well as some abstract operations to deal with media. How do we offer these operations to users? This is explained by the following design decision.

> **DES 086: Access to a medium is done using the `MediumStore`**
> The reading and writing access to a medium (both random-access as well as byte stream according to DES 086) is offered via interface `MediumStore` with the operations listed in table 11.3.
>
> **Begründung:** A further subdivision of functionality into more than one interface is neither necessary nor helpful. It would just be an unneccessary complex API, and despite the single interface, the implementation can still be modularized as needed. The individual operations are motivated in the table itself.
>
> **Nachteile:** No disadvantages known

Operation	Description	Features and motivation random-access	Features and motivation InputStream
cache(x, n)	Buffers n bytes according to DES 086 and DES 086 permanently in the internal cache, starting at the given offset x. If caching is disabled (specifically for byte array media, see DES 086), this call is ignored. The method might reach the end of medium which it signals as an exception.	User code can prefetch data to work on it later, he himself gets the possibility to efficiently read and process data.	If x is bigger than the last read end position, the bytes up to the new offset are read and possibly cached. If x is smaller instead, a InvalidMediumReferenceException is thrown. The last read end position is advanced correspondingly.
getCachedByteCountAt(x)	According to DES 086 and DES 086, it provides the number of bytes that are consecutively cached at offset x.	See cache. User (and test) code must be able to additionally check whether enough data is already buffered or not.	See random-access.
getMedium()	Returns the Medium instance this MediumStore is associated with.		
getData(x, n)	Reads n bytes at offset x according to DES 086, DES 086, DES 086.	Calls cache to ensure all bytes are cached, then returns the data in a consolidated ByteBuffer.	Same as for random-access media. This indicates that this method also might throw an InvalidMediumReferenceException.

Operation	Description	Features and motivation random-access	Features and motivation InputStream
`isAtEndOfMedium(x)`	Checks if offset x is at the end of the MEDIUM.	Based on this knowledge, the user code can skip further reading and does not need to check for exceptions.	The provided offset is ignored, it is tried to read bytes from current offset. Is this resulting in return code -1, we are at the end of the stream, otherwise the byte is added to the cache.
`insertData(x, data)`	Implements the writing operation *insert* according to DES 086, DES 086, DES 086, DES 086, DES 086: Adds data at the given offset x, consecutive bytes are shifted "to the back", the changes first get written only with `flush()`.	The insertion of new metadata is a common case in `jMeta` and must be supported.	`ReadOnlyMediumException`
`removeData(x, n)`	Implements the writing operation *remove* according to DES 086, DES 086, DES 086, DES 086, DES 086: Removes n bytes at offset x. Consecutive bytes are shifted "to front", the changes first get written only with `flush()`	Removing existing metadata is a standard case in `jMeta` and must be supported.	`ReadOnlyMediumException`

Operation	Description	Features and motivation random-access	Features and motivation InputStream
`replaceData(x, n, data)`	Implements the writing operation *replace* according to DES 086, DES 086, DES 086, DES 086, DES 086: Replaces n bytes at offset x with new bytes of length m. The changes first get written only with `flush()`	It often happens that − instead of entirely removing or newly inserting data − existing data must be overwritten. This is - especially at the beginning of a file - a much more efficient operation than insertion and deletion and must thus directly be supported.	`ReadOnlyMediumException`
`flush()`	Implements the writing operation *flush* according to DES 086: All *changed* data currently in the temporary buffer are written in a suitable way to the external medium. It cannot be guaranteed that this operation is atomic.	This is a practical implementation of DES 086: While `insertData()`, `removeData()` and `replaceData()` only write into a temporary buffer, this call directly writes to the external medium.	`ReadOnlyMediumException`
`createMediumReference(x)`	Creates a new `MediumOffset` instance for the given offset x according to DES 086	Is needed for random-access	Is needed for `InputStreams`
`undo(mediumAction)`	Undoes the changes of the given `MediumAction` according to DES 086, as far as it is still pending.	Is needed for random-access	`InvalidMediumActionException`

Operation	Description	Features and motivation random-access	Features and motivation InputStream
`open()`	Opens access to the medium	Explicit open instead of constructor better for testing	Explicit open instead of constructor better for testing
`close()`	Closes all internal resources according to DES 086, clears the complete cache contents and other internal data structures	See DES 086	See DES 086
`isClosed()`	Allows users to check if the medium is already closed and thus cannot be accessed anymore (returns true), or it is still accessible (returns false).	See DES 086	See DES 086

Table 11.3.: Operations of the `Media` API

The component interface

How are the public functions exposed to the outside world? There must be a functionality that creates a `MediumStore` instance for a given `Medium`. The API for this looks as follows:

> *DES 087:* `MediaAPI` **is the central entry point with creation functions for** `MediumStores`
> The interface `MediaAPI` offers the central entry point for the component `Media`. Using the method `createMediumStore()`, users can create an `MediumStore` instance.
>
> **Begründung:** The necessity for a further interface in addition to `MediumStore` is clear enough: A `MediumStore` refers to just a single "medium access session" for a medium, and of course users want to be able to open multiple media at the same time using `Media`. Pushing creation functions into `MediumStore` is not considered good practice as it would decrease comprehensibilty.
>
> **Nachteile:** No disadvantages known

Error Handling

In general violations of the interface contract according to DES 087 are acquitted with a runtime exception.

The following table summarizes all further error situations when working with `Media`:

Error Scenario	Description	Reaction `jMeta`	API method
Medium is already locked	The medium is already locked by another process. `jMeta` cannot work with the medium. It is the burden of the caller to ensure, that the medium is not used in parallel.	It is an abnormal situation, thus a `MediumAccessException` runtime exception is thrown.	`MediaAPI` `.createMediumStore()`
Unknowm media type	A `Medium` implementation is specified by the caller which is unsupported.	This is an abnormal situation violating the interface contract, thus the same exception as for contract violations is thrown.	`MediaAPI` `.createMediumStore()`

Write to read-only medium	The user-provided `Medium` implementation is read-only, thus it only allowes read access.	If the user nevertheless tries to write, this is an abnormal sitation and is signalled by a `ReadOnlyMediumException` runtime exception.	`MediumStore`
			`.flush()`, `Medium-`
			`Store .insertData()`,
			`MediumStore`
			`.removeData()`,
			`MediumStore`
			`.replaceData()`

Consecutive write calls overlap	Concecutive calls to `insertData`, `removeData` or `replaceData` before a `flush` overlap in an invalid way, see DES 087, DES 087, DES 087, DES 087, DES 087	Is acquitted with an `InvalidOverlappingWriteException` runtime exception.	`MediumStore`
			`.removeData()`,
			`MediumStore`
			`.replaceData()`

Error Scenario	Description	Reaction jMeta	API method
Invalid cache offset	With `cache()` it is tried for an `InputStream` to cache an offset that is smaller than the last read offset.	This is a wrong usage of the API, thus it results in an `InvalidMediumReferenceException` runtime exception.	`MediumStore .cache()`, Medium-Store `.getData()`
End of medium during reading	Of course each medium has an end sometimes. When reading, this end can be reached. When writing, this is not actually possible - there, we assume that all output media virtually are unlimited. If there is no more memory for writing, `Media` usually reacts with a `MediumAccessException` following an `IOException`. It cannot be requested from the calling code during reading, that it knows where the end of the input medium is. Reaching its end during reading can be an error, but it needs not - this depends on the current usage situation. The calling code thus must handle this depending on current context.	Because it is not necessarily an abnormal situation, a `EndOfMediumException` checked exception is thrown.	`MediumStore .cache()`, Medium-Store `.getData()`

Error Scenario	Description	Reaction jMeta	API method
Stream data not available	Data requested with `getData()` for a given offset is not available (anymore) in the cache, and the underlying medium is an `InputStream`.	This is a wrong usage of the API, thus it results in an `InvalidMediumReferenceException`, a runtime exception.	`MediumStore .getData()`
Unknown or invalid `MediumAction`	The user passes an unknown or invalid `MediumAction` to any operation	This is an abnormal situation and is acquitted with the runtime exception `InvalidMediumActionException`	`MediumStore.undo()`
`IOException` in the implementation	The Java implementation use throws an `IOException`, at any place where none of the already presented error situations are involved.	It is an abnormal situation, thus a `MediumAccessException` runtime exception is thrown.	`MediumStore .cache()`, `MediumStore .getData()`, `MediumStore .isAtEndOfMedium()`, `MediumStore .flush()`
The `MediumStore` was already closed using `close()`	`MediumStoreClosedException`, a runtime exception	`MediumStoreClosedException`, a runtime exception	all

Table 11.4.: Error handling in the component `Media`

To summarize:

> **DES 088: Reaching the end of medium is not necessarily an error, other problems with I/O are seen as abnormal events.**
> `Media` sees achieving at the end of a medium not as abnormal event, but it must be handled according to the current context by the user code. `jMeta` assumes output media to be virtually unlimited and thus does not implement any means of treating end of medium situations when writing (also in accordance to the Java API).
> All other error sitations in `Media` are abnormal situations according to table 11.4.
>
> **Begründung:** See table
>
> **Nachteile:** No disadvantages known

11.1.3. Implementation Design

Medium Access

Access to the MEDIUM is implemented in own classes, as the following design decision states:

DES 089: **Interface `MediumAccessor` with implementations for each Media type access**

Access to a Medium is possible via an interface `MediumAccessor`, doing a great deal of ensuring DES 089. It offest the following primitives:

- `getMedium`: Returns the medium this instance is working on.

- `open`: Opens the medium for access. Opening creates an exclusive lock on the medium, as far as the medium supports this (see DES 089, DES 089, DES 089).

- `isOpened`: Check if the medium is opened.

- `close`: Close the medium for access. A closed medium cannot be used anymore.

- `setCurrentPosition`: Sets the current position for the next `read`, `write`, `truncate` or `isAtEndOfMedium` call. Is ignored for non-random-access media.

- `getCurrentPosition`: gets the current position on the medium where the next `read`, `write`, `truncate` or `isAtEndOfMedium` will be executed.

- `read` at the current position: Read n bytes from external medium by explicit access from the current position, return the bytes in a `ByteBuffer`. Advances the current position by the number of read bytes.

- `write` at the current position: Writes n bytes to the external medium at the current position passed in a `ByteBuffer`. Throws an exception for read-only media, especially for `InputStream`. Advances the current position by the number of read bytes.

- `truncate` to new end offset at the current position: Truncates the medium to end at the current position. Throws an exception for read-only media, especially for `InputStream`.

- `isAtEndOfMedium`: Check if the current position is at end of the Medium.

There is one implementation of this interface for each distinct Medium type. `MediumStore` exclusively accesses the Medium only via this interface.

Begründung: `MediumStore` itself can deal with caching and the complex implementation of writing functionality independently from the concrete medium, while the actual medium access can be abstracted away by concrete implementations generically. Classical separation of concerns to increase maintainability and comprehensibility of the solution.
Regarding the offset handling for read: This is necessary to ensure readable and non-confusing use for non-random-access media. In that way, the user does not assume the medium is actually read-only.

Nachteile: No disadvantages known

Management of `MediumOffset` instances

According to DES 089, `MediumOffset` instances must be maintained centrally by
`MediumStore`. At the same time, we can have multiple `MediumOffset` instances
referring to the same offset of the same medium, but actually refer to different data
- in the special case of the methode `insertData`. New data is inserted subsequently
at the same offset with `flush()`, see DES 089. In the end, the `MediumOffset`
instances must be automatically updated with `flush()`, as described in DES 089
and DES 089.

Thus, these things follow:

> ***DES 090:*** **No pooling of `MediumOffset` instances for the same offsets is**
> **possible**
> In contrast to Java strings, the reuse of `MediumOffset` instances in
> `createMediumReference()` for same offsets is not possible, i.e. if an
> `MediumOffset` instance for offset x has already been created, the same instance
> cannot be returned for the same offset on the next call. A new `MediumOffset`
> instance must be created instead.
>
> **Begründung:** Assum we use pooling. Furthermore, assume there are two
> inserts of lengths n_1 and n_2 at the same offset x scheduled via `insertData()`.
> The internal implementation would only have a single instance of `MediumOffset`
> for offset x. `flush()` must keep the offset of the first insertion unchanged, as the
> data of this first insertion remain there. Howeder, the offset of the second
> insertion must be changed, as these inserted bytes are actually located at offset
> $x + n_1$ after `flush()`.
>
> **Nachteile:** For many created `MediumOffset` objects, there could be a bigger
> memory footprint.

Furthermore, the `MediumOffset` objects must be maintained in a dedicated data
structure:

> ***DES 091:*** **All instances ever created with `createMediumReference()` are**
> **maintained in a dedicated data structure that allows duplicates**
> All instances are held in a data structure that allows duplicates. It must be
> dedicated, i.e. only be used for storing all ever created `MediumOffset` objects.
>
> **Begründung:** Dupllicates must be possible due to DES 091. We cannot mix
> that data structure with the caching or pending change data structures, as on
> the one hand side there will be always more `MediumOffset` instances, than cache
> entries or pending changes, and on the other hand cache and pending change list
> could be cleared, while the `MediumOffset` instances must be kept until the
> explicit close of the mediums.
>
> **Nachteile:** No disadvantages known

Are these entries of the dedicated data structure indicated by DES 091 in any way sorted?

***DES 092:* Unsorted ArrayList for keeping the `MediumOffset` instances**
We use an `ArrayList` as data structure for maintaining all `MediumOffset` instances. Insertion of `MediumOffset` instances is done in creation order. The list is unsorted.

Begründung: A list allows for duplicates. Sorting of the list after each addition would lead to $O(n \log n)$ runtime complexity on average when creating a new `MediumOffset` instance, if n is the current size of the list. Ascending sort order by offset would be a bit more efficient for `flush()`, but does hardly justify the effort during insertion, because the creation of a `MediumOffset` instance is usually much more commonly done than a `flush()`. Following approaches have been rejected especially:

- A `Map<Long, List<MediumOffset>>` with offsets as key and all `MediumOffset` instances for the offset as value won't work, as the offsets would need to be shifted on each insertion, i.e. the keys of the map would either need to be `MediumOffset` instances again, or would need to be updated expensively.

- A `TreeSet<MediumOffset>` can be excluded as it does not allow duplicates.

- A combination of a `TreeSet` with a special `Comparator`, which assumes `MediumOffset` instances only to be equal, if they are the same objects, and as bigger, if the offset is the same, but the object is different, would accept such "duplicates" with the same offsets and ensure correct sorting for every insert. However, the `Set` then is incompatible with `equals`, what is not a best practice according to the javadocs. Secondly: More time required for insertion as mentioned.

Nachteile: Finding all `MediumOffset` instances within the `flush()` implementation, that are bigger than a given offset has $O(n)$ complexity, which can however be tolerated.

To handle the complexity of `MediumStore` we decide:

> **DES 093:** **The class `MediumOffsetFactory` is used for maintaining `MediumOffset` instances**
> `MediumOffsetFactory` implements the design decisions DES 093, DES 093 as well as DES 093. It offers following methods:
>
> - `createMediumReference()` to create `MediumOffset` instances
>
> - `updateReferences()` for implementation of DES 093, where a `MediumAction` instance is passed
>
> - `getAllReferences()` returns all maintained instances
>
> - `getAllReferencesInRegion()` returns all maintained instances with given offset range
>
> - `getAllReferencesBehindOrEqual()` returns all maintained instances with offsets bigger than the given offset
>
> - `clear()` removes all maintained instances
>
> **Begründung:** Reduction of total complexity of the `MediumStore`.
>
> **Nachteile:** No disadvantages known

The last question for `MediumOffset` instances that still has to be answered: How to deal with the method `advance()` mentioned in DES 093. It creates `MediumOffset` instances. Do they have to be maintained in `MediumOffsetFactory`, too?

> **DES 094:** **The `MediumOffset` instances created with `MediumOffset.advance()` need to be maintained with `MediumOffsetFactory`, too.**
> Initially, the new `MediumOffset` instance must get a reference to its creator, i.e. `MediumOffsetFactory`, during construction. To still enable a simple creation of instances of `MediumOffset` implementation classes (e.g. in unit tests), the constructor is public.
>
> **Begründung:** The client code can arbitrarily use `MediumOffset.advance()`, and the returned references can be used as usual, e.g. for newly created data blocks. Thus it is clear that even these references are auto-corrected with `MediumOffsetFactory.updateReferences()`.
>
> **Nachteile:** Close coupling between `MediumOffset` and `MediumOffsetFactory`, as both are knowing each other.

Internal Data Structures for Caching

The cache on first sight maintains data bytes per offset, always assuming that the data in cache is exactly identical to the data on the external medium, ac-

cording to DES 094. It was already defined that there is an explicit `Medium-Store.cache()` method for reading data into the cache and a method `Medium-Store.getCachedByteCount()` for querying connected bytes from the cache (see table 11.3, as well as DES 094 and DES 094). Querying data from the cache is done using `MediumStore.getData()`, which can on the one hand skip the cache, on the other hand it can automatically update the cache with missing data (DES 094 and DES 094). Finally, the maximum cache size can be set or caching can even be entirely inactive (see DES 094 and DES 094).

In most cases we want to query which parts of data to read, write or remove is within the cache. The cache might be fragmented arbitrarily due to multiple fill operations. The make the code easier to understand and maintain, we create a specific class for representing the so called regions, i.e. added cache fragments:

DES 095: **Class** `MediumRegion` **for consecutive regions of a medium,
especially also for cache regions**
The class `MediumRegion` represents a consecutive byte range with start offset,
size and contained bytes of a medium, that may or may not be cached. It offers
the following methods:

- `getStartReference()`: Query start `MediumOffset` of the region

- `getSize()`: Query length of the region

- `isCached()`: Returns true if cached, false otherwise

- `getBytes()`: Returns null if the region is not cached, otherwise the
  `ByteBuffer` with the cached region data

- `isContained()`: Returns true if the given `MediumOffset` is contained
  within the region, false otherwise

- `overlapsOtherRegionAtBack()`: Returns true if the this region overlaps
  the other region at its back, i.e. shares bytes with it at its end, otherwise
  returns false.

- `overlapsOtherRegionAtFront()`: Returns true if the this region overlaps
  the other region at its front, i.e. shares bytes with it at its front, otherwise
  returns false.

- `getOverlappingByteCount()`: Returns the number of bytes that this
  region shares with another region or zero if it does not share any bytes
  with it.

- `split()`: Splits this region into two regions at the given offset

Begründung: The cache regions and the non-cached regions of the medium can
be treated in the same way. Implementing caching is easier when not based on
primitive types (e.g. byte[]) only, but using this helper class.

Nachteile: No disadvantages known

Maintenance of cache content is done by a helper class:

> **DES 096:** **Cache maintenance by `MediumCache`, ensuring maximum cache size and no overlapping regions**
>
> Cache maintenance is done by the class `MediumCache`. This class has the following invariants at any point in time before and after public method calls:
>
> - The `MediumRegion`s stored in the cache do never overlap
>
> - The maximum cache size is never exceeded
>
> - The maximum size of a cache region is never exceeded by any region
>
> It offers the following methods:
>
> - `getAllCachedRegions()`: Returns a list of all cached `MediumRegion` instances currently contained in this cache, ordered by offset ascending
>
> - `getCachedByteCountAt()`: Returns the number of bytes cached consecutively starting from offset x
>
> - `getRegionsInRange()`: Returns a list of `MediumRegion` instances overlapping the offset range $[x, x + n]$, which represent the cached and non-cached ranges within the offset range. I.e. whenever there is a gap in the cache, this gap is also represented by a single `MediumRegion` instance without data
>
> - `addRegion()`: Adds a `MediumRegion` to the cache. Previously cached data is overridden.
>
> - `clear()`: Frees all data in the cache
>
> - `getMaxRegionSizeInBytes()`: Returns the maximum size of a region in bytes. Default is `Integer.MAX_VALUE`, which is represented by a constant named `UNLIMITED_CACHE_REGION_SIZE`. The cached regions will have at most the given size.
>
> - `getMaxCacheSizeInBytes()`: Returns the maximum size of the cache in bytes. Default is `Long.MAX_VALUE`, which is represented by a constant named `UNLIMITED_CACHE_SIZE`. The cache size will at no time exceed this number of bytes.
>
> - `getCurrentCacheSizeInBytes()`: Returns the current size of the cache in bytes.
>
> **Begründung:** Reducing complexity of `MediumStore`
>
> **Nachteile:** No disadvantages known

For the cache sizes, we saw already that we can query the maximum and current cache size as well as the maximum region size. However, why can we not change the maximum sizes dynamically?

DES 097: **The maximum cache and maximum region size of a cache instance can never be changed throughout its life time.**
The maximum cache size and the maximum region size are passed to the constructor of the `MediumCache` class and they must not be changed later.

Begründung: Otherwise complex methods for reorganizing the cache are necessary, splitting and discarding existing regions. It is very unlikely that the user needs to change the cache size during accessing the medium. It if fully sufficient that he can configure the maximum size of the cache and its regions before the first access to the medium.

Nachteile: No disadvantages known

How are the cache regions internally managed?

DES 098: **A `TreeMap` is used for managing the cache contents, an additional `LinkedList` for freeing up according to FIFO**
A `TreeMap<MediumOffset, MediumRegion>` is used for managing the cache contents. An additional `LinkedList` is used for freeing up cache data according to FIFO.

Begründung: Content must be read based on offsets. Thus a data structure sorted by offset is necessary. It allows the efficient retrieval of all `MediumRegion`s bigger or smaller than a given offest. This operation should most probably need a runtime complexity of only $O(log(n))$ instead of $O(n)$.
The `LinkedList` is necessary to efficiently remove the first added cache regions when freeing up is necessary due to max cache size reached, see DES 098.

Nachteile: No disadvantages known

We should also think about cache fragementation. Let us assume that, by subsequent calls to `addRegion()`, we would add a single byte to the cache 20 times for a consecutive offset range. Will this result in 20 different `Medium-Region`s with a length of one byte each? The same question arises for calls to `MediumStore.getData()`, which spans over an offset range with gaps in the cache coverage. Assume we have a cache that contains 20 bytes starting at offset x, further 50 bytes at offset $y := x + 30$, i.e. it has a gap of 10 bytes between the two regions. If there is a now a call to `MediumStore.getData()` for range $x - 10$ with length of 100, we would result in five regions:

- Region 1: $[x - 10, x)$ not in the cache

- Region 2: $[x, x + 20)$ in the cache

- Region 3: $[x + 20, y)$ not in the cache

- Region 4: $[y, y + 50)$ in the cache

- Region 5: $[y + 50, y + 60)$ not in the cache

`MediumStore.getData()` will then add regions 1, 3 and 5 to the cache, according to DES 098. So, do we have 5 `MediumRegion`s in the cache after the call? Another extreme case is that the user reads 20 single bytes each with an offset gap of just one byte to the next one. This would result in 20 cache regions each with a size of one byte.

To ease the implementation complexity, we nevertheless decide:

***DES 099:* Fragmentation of cache regions is not actively avoided**
`Media` does not try to mitigate or avoid the following situations:

- Direct consecutive cache regions are not joined, even if their total size is smaller than the maximum allowed region size

- "Nearby" but unconnected (i.e. non-consective) cache regions of small sizes are not handled in any special way.

Begründung: It would lead to even higher complexity of the implementation of `addRegion()`.
In contrast to that high complexity, we can ask the caller to ensure that he only adds data for reasonably connected offset ranges.

Nachteile: No disadvantages known

Internal Data Structures for Managing Pending Changes

For the two-stage write protocol, changes scheduled via `insertData()`, `removeData()` and `replaceData()` must be managed in a reasonable way, such that they later can be processed during `flush()`. Any change is represented as a `MediumAction`.

We first state the following:

DES 100: `MediumAction` **has a schedule sequence number for knowing the schedule order of actions**
`MediumAction` defines a schedule sequence number (starting at 0) for distinguishing which action has been scheduled earlier. It is incremented by any scheduled action (no matter which type) by 1. The schedule sequence number is "global" for the same medium in a sense that it is simply incremented for each change, no matter what change it is and if there was a flush already or not.

Begründung: Two distinct `MediumAction` instances of type `insert` referring to the same offset cannot be sorted without this mechanism (see DES 100).

Nachteile: No disadvantages known

We now have to define comparisons between two `MediumAction`s in a reasonable way, as sorted data structures for efficient retrieval and iteration in order can be used correspondingly:

DES 101: **Comparisons of** MediumActions **is done based on**
MediumOffset **and the sequence number**
A MediumAction a is smaller than another MediumAction b according to Javas
compareTo, if and only if one of the following criteria are met:

- The MediumOffset of a is smaller than the MediumOffset of b,

- Or the MediumOffset of a is equal to the MediumOffset of b, and the
  sequence number of a is smaller than the sequence number of b

A MediumAction a is equal to a MediumAction b according to Javas equals and
compareTo, if all attributes of a are equal to all attributes of b (in terms of
equals).
A MediumAction a is bigger than a MediumAction b according to Javas
compareTo, if a is neither smaller than b nor equals b. This is especially true if
the MediumOffset is bigger, or for equal MediumOffsets, if the sequence number
is bigger. Furthermore it is defined: If MediumOffsets and sequence numbers are
identical, then a is still bigger than b in the case that any of the other attribute
of the MediumActions differs.

Begründung: Sorting of MediumActions should be done according to their
order on the medium (i.e. their MediumOffsets) and creation order (i.e. their
sequence number), because behaviour of consecutive operations is based on call
order, according to DES 101, DES 101 and DES 101. In addition, the
MediumActions must be processesed in a defined order during flush. equals
must return true exactly in the case that compareTo returns 0.

Nachteile: Might cause confusion, as smaller and bigger are not symmetric.
The implementation must thus ensure that MediumActions with same offset
always get different sequence numbers that strictly increase with creation order.

Now we can define in which way the MediumActions are stored:

DES 102: MediumActions **are stored in a sorted data structure without**
duplicates
The MediumActions created before a flush() are held in a datastructure sorted
by offset and sequence number (according to DES 102), which does not allow
duplicates (e.g. TreeSet).

Begründung: The sort order is necessary for in-order-processing via flush(),
two MediumActions with same offset, same sequence number and same type
should not show up twice.

Nachteile: No disadvantages known

Now regarding management of MediumActions:

DES 103: **For managing MediumActions, the class MediumChangeManager is responsible**
For managing MediumActions, the class MediumChangeManager is defined, which internally implements DES 103, with following methods:

- scheduleInsert() for scheduling an *insert*, implements DES 103, gets a MediumRegion as parameter and returns a MediumAction of the given type and with correct sequence number, i.e. should there be other actions at the same offset, the new action is guaranteed to have a sequence number higher than the action with the biggest sequence number already present for the same offset.

- scheduleRemove() for scheduling a *remove*, implements DES 103, gets a MediumRegion as parameter and returns a MediumAction of the given type and with correct sequence number, i.e. should there be other actions at the same offset, the new action is guaranteed to have a sequence number higher than the action with the biggest sequence number already present for the same offset.

- scheduleReplace() for scheduling an *replace*, implements DES 103, gets a MediumRegion and the length of the range to replace as parameter, returns a MediumAction of the given type and with correct sequence number, i.e. should there be other actions at the same offset, the new action is guaranteed to have a sequence number higher than the action with the biggest sequence number already present for the same offset.

- undo() for undoing actions, implements DES 103

- iterator() returns an Iterator<MediumAction> for reading traversation of the changes in correct order, Iterator.remove() is not implemented

- clearAll() removes all changes

Here, the three schedule methods create MediumActions according to DES 103 and DES 103.

Begründung: Reduction of overall complexity of MediumStore.
The iterator allows reading of changes in order, but is not needed for processing, as we see later. remove on this iterator is not necessary, as undo() can undo an action.

Nachteile: No disadvantages known

At the end, we highlight some commonalities between MediumActions and MediumRegions, and define:

> **DES 104:** MediumAction **aggregates a** MediumRegion **instance**
> MediumAction aggregate a MediumRegion instance which holds that offset and
> length of the action, BUT NOT the bytes related to the action itself, which are
> held in a separate attribute of the MediumAction.
>
> **Begründung:** MediumAction needs a start MediumOffset, a length of the
> change as well as possibly the bytes to change, if any. However, we only
> implement start and length in form of a MediumRegion instance. You can
> interpret MediumAction as a class that refers to a MediumRegion. It is a classical
> "has a" instead of an "is a" relationship, which requires aggregation instead of
> inheritance. The reason to not keep the bytes in the aggregated MediumRegion
> but in the MediumAction itself lies in the special form of the replace operation.
> For detecting non-allowed overlaps, only the number of bytes to replace is
> important (see DES 104 and DES 104) and not the replacement bytes
> themselves. In that way, we can get a common implementation of overlap
> detection.
>
> **Nachteile:** No disadvantages known

Implementation of flush

The most complex functionality of MediumStore is flush(), because:

- flush() must iterate all pending changes,

- align them with the current cache content,

- cut reasonable blocks of the data bytes to write,

- update all MediumOffset and MediumAction instances,

- update the cache

We can add that the writing operations have some additional oddities:

- insertData() and removeData() require that data behind the insertion or
  removal offset is read and written again

- replaceData() should also not be underestimated, as depending on the
  number of existing bytes to replaces with a different number of new bytes,
  it can either lead to no shifts at all (number of bytes to replace equal to
  number of replacement bytes), to an insert (number of bytes to replace
  smaller than number of replacement bytes) or a remove (number of bytes to
  replace bigger than number of replacement bytes)

- If these operations are done at the beginning of files, reading data up to the
  end of file is possibly not possible in one large chunk, as it could lead to
  OutOfMemoryError for large files, thus block-wise reading is necessary

- For this block-wise reading, the writing operations differ from each other:

– For an `insertData()` of n bytes at offset x, data must be read and written block-wise starting from the end of medium down to offset x. I.e. first the last k bytes of the medium at offset r are read and then written to offset $r + k$, then k bytes at offset $r - k$ are read, to be written at r and so on until offset x. Another way is not working if you do not want to overwrite and thus lose existing bytes.

– For `removeData()` of n bytes at offset x, we must read and write data starting at offset $x + n$ block-wise until the end of the medium. First, k bytes at offset $x + n$ are read and then written at x, then k bytes at offset $x + n + k$ are read to be written to offset $x + k$ and so on, until the last byte of the medium.

– For `replaceData()` we have to distinguish corresponding cases, it could either behave like `insert` or `remove`, or a simple overwrite (if number of bytes to replace equals number of replacement bytes).

We can first confirm that the configuration of a maximum read write block size for writing is necessary:

> ***DES 105:* A maximum read-write block size must be configurable for the user**
> It must be between 1 and N (any integer) bytes
>
> **Begründung:** Necessary due to the block-wise reading and writing operations behind affected regions caused by inserts and removes. By making it configurable, the user can himself decide how much bytes should be processed in a single pass.
>
> **Nachteile:** No disadvantages known

Finding out wich operations must be executed during a flush is a complex task. We need to perform this complex task within a method:

DES 106: `createFlushPlan()` in MediumChangeManager **creates a**
read-write-plan for a flush in form of a `List<MediumAction>`
`createFlushPlan()` creates a read-write-plan for a flush and returns a
`List<MediumAction>`. The read-write-plan contains the actions to be executed
in the given order. The list of possible actions is extended by `READ`, `WRITE` and
`TRUNCATE`. Which are defined as:

- READ: primitive reading of n bytes starting at offset x

- WRITE: primitive writing (i.e. overwriting) of n bytes starting at offset x

- TRUNCATE: explicit shortening of a file, which is especially necessary for
  removing data

Each returned `READ` action must be followed by a `WRITE` action, otherwise the
plan is invalid. `INSERT` and `REPLACE` operations lead to `WRITE` actions. For all
`READ` and `WRITE` actions: the number of bytes is between 0 and the (configured)
maximum read-write block size. `createFlushPlan()` also returns the original
`REMOVE`, `REPLACE` and `INSERT` actions explicitly in the plan, although they are
implemented implicitly by `READ` and `WRITE` actions.
The read-write-plan thus contains `MediumAction`s in addition to those caused by
scheduling actions by a user. These additional actions are, however, not added
to the internal data structures of the `MediumChangeManager`.
The created plan is the basis for processing in `flush` afterwards.

Begründung: Determining the necessary operations is a complex process,
which should be done separately. A direct execution of the plan would be an
alternative, but testability of the code would heavily suffer.
`MediumChangeManager` is the correct place for this operation, as here all
`MediumAction`s are managed anyways. The additional `MediumAction`s in the
plan are not added to any internal data structures to ensure the operation is
stateless and ideally repeatable.
Adding another `WRITE` primitive seems unnecessary, as there is already an
operation named `REPLACE`. However, `WRITE` differs insofar as the bytes to write
might not yet be known when the action is created, in contrast to `REPLACE`.

Nachteile: No disadvantages known

Next, we should clarify how the cache is involved in `flush()`. In case caching
is enabled for the medium, we have the following points to look at:

- If bytes are added to the medium with `INSERT` or `REPLACE`, these bytes must
  also be added to the cache

- If bytes are removed from the medium with `REMOVE` or `REPLACE`, these bytes
  must also be removed from the cache

- If bytes behind a change must be read (and written), they should also be
  directly added to the cache to save future medium accesses in these ranges

- Furthermore, if bytes behind a change must be read, it must also be checked if they are already contained in the cache, such that an explicit `READ` on the external medium is only necessary if these bytes are not cached

- It is not yet clear if a specific handling of `TRUNCATE` is necessary

For the last point, we define the following:

DES 107: **`READ` operations in `flush` prefer cached data and update the cache if not already contained - We implement this using `getData`**
Whenever `flush` processes a `READ` action coming from the flush plan, it first checks if the data to read is fully cached. If it is, it takes the data from the cache. If it is not, it reads the data directly from the external medium and adds it to the cache.
This is exactly what getData already does - so we simply call this method. If an `EndOfMediumException` occurs during reading, this is unexpected and will lead to an `IllegalStateException` thrown.

Begründung: We want to use cached data as much as possible and avoid unnecessary medium accesses.

Nachteile: No disadvantages known

Correspondingly, this is how we treat `INSERT` and inserting `REPLACE` in `flush` regarding caching:

DES 108: **`INSERT` and inserting `REPLACE` operations in `flush` add their data to the cache**
Whenever `flush` processes an `INSERT` or `REPLACE` action coming from the flush plan, it adds all bytes to insert or replacement bytes from these actions to the cache.

Begründung: We want to use cached data as much as possible and avoid unnecessary medium accesses.

Nachteile: No disadvantages known

Very similar for `REMOVE` and `REPLACE`:

> **DES 109:** REMOVE and REPLACE operations in `flush` remove their removed or replaced ranges from the cache
>
> Whenever `flush` processes a REMOVE or REPLACE action coming from the flush plan, it removes all bytes to remove or replace from the cache.
>
> **Begründung:** Avoid cache corruption if old data is still present. In best case, the code directly fails when trying to add new data, in worst case the stale removed data remains in the cache and is later returned by read operations despite the medium already changed.
>
> **Nachteile:** No disadvantages known

Do we have to do anything with the cache regarding a TRUNCATE action? This is answered in the following design decision:

> **DES 110: For a TRUNCATE, nothing is to be done related to caching**
>
> The cache does not require any updates when processing a TRUNCATE action in `flush`.
>
> **Begründung:** Although it first might seem that, because TRUNCATE shortens the medium, no cache updates are necessary for any cached bytes at the end of the medium. This is because the cache is implicitly cleaned by handling the REMOVE that leads to the truncate. This consists of removing cached bytes for the removed region as well as updating `MediumOffset`s of any data cached behind the removed region.
>
> **Nachteile:** No disadvantages known

We still have the topic to update any already created `MediumOffset`s when processing INSERTs, REMOVEs and REPLACEs according to design decision DES 110. When do we need to perform these changes? The first part of the answer is given in the following design decision:

> ***DES 111:*** `flush` **processes the flush plan in two phases: Medium**
> **access phase and cache update phase**
> First of all, flush iterates all `MediumActions` in the flush plan in order and
> executes any `READ`, `WRITE` and `TRUNCATE` operations. So this can be called the
> *medium access phase*. In the second phase, all `MediumActions` are iterated again,
> while the cache is updated, the `MediumActions` are set to done and the
> `MediumOffsets` are updated in correspondence with the changes.
>
> **Begründung:** Why not performing everything within the same loop, i.e. just
> once iterating the `MediumActions`? This would mean to e.g. first execute an
> `INSERT` action, and then update all references. The problem: The flush plan
> might still contain READ and WRITE operations which are referring the offsets
> on the current medium. Calling `MediumOffsetFactory.updateReferences()`
> already now would also update these references, and they would be pointing to
> the wrong bytes! Thus, we must first process all `READ` (including adding of the
> read bytes to the cache), `WRITE` and `TRUNCATE` operations with their original
> offsets. For the caching updates in terms of `INSERT`, `REPLACE` And `REMOVE`, there
> are additional constraints that make it necessary to do it in the second phase.
> These are detailled in the next design decision.
>
> **Nachteile:** No disadvantages known

The second part of the answer when to perform `MediumOffsetFactory.updateReferences()`
comes here. Some things need to be kept in mind when updating the cache, which
depends on the action type:

> ***DES 112:*** **For `INSERT`s and the replacement bytes of a `REPLACE`,**
> **`MediumOffset`s are updated *BEFORE* the cache is updated, for `REMOVE`s**
> **and the replaced bytes of a `REPLACE` they are updated *AFTERWARDS***
> For `INSERT`s and `REPLACE`s, any `MediumOffset`s already created and maintained
> in the `MediumOffsetFactory` are updated first, which essentially increases the
> offsets of any `MediumOffset`s behind the insertion or replacement offset by the
> number of bytes inserted or the number of replacement bytes. Only after this,
> the data newly inserted or the replacement bytes can be added to the cache.
> In contrast to this, when `REMOVE`s and the replaced region of a `REPLACE` are
> processed, first of all, the bytes to remove or replace, if present in the cache,
> need to be removed from it. Only then, all `MediumOffset`s behind the remove or
> replace offset need to be decreased by the number of removed or replaced bytes
> (or fall back to remove or replace offset, if within the removed or replaced range).
>
> **Begründung:** For `INSERT`s: If we add the inserted (or replacement) data to the
> cache before updating reference, the following would happen: Assume there are
> bytes already cached directly starting at the insertion offset. They would be
> superseded by the inserted data, i.e. thrown out of the cache. Then only all
> remaining data with higher offsets in the cache would be updated. This way, we
> would essentially lose cached data unnecessarily and increase the complexity of
> cache management needed at runtime a bit.
> For `REMOVE`s: If we would first update the `MediumOffset`s here, the following
> could happen: Assume we have two consecutive cached regions within the region
> to remove. For both regions, its offset would be updated to point to the remove
> offset. So we would have two regions cached with the same start offset, which
> leaves the cache inconsistent. Instead, we first remove all cached regions within
> the removed range, then we update any remaining regions (those behind the
> removed range).
>
> **Nachteile:** No disadvantages known

The question for the complex `flush` operation now is: Do we need to do any-
thing special for error handling? First of all we should think of: What could
happen? In detail, there are two reasonable scenarios what could go wrong:

- There is a programming error in the library, and this leads to a runtime
  exception

- There is a problem during accessing the medium, may it by a HD failure or
  that another process accesses the medium in parallel

Both cases can be considered fatal. Would a retry make sense? Probably yes,
but most often: Probably no. Should we support in performing a retry? Probably
also no:

> **DES 113: No specific error handling is done in `flush` itself**
> There is no try-catch block within `flush` trying to handle any runtime errors. These errors are directly thrown up to the using code. The `flush` implementation does not perform any specific measures to ensure or allow retry or "recovery" mechanisms.
>
> **Begründung:** First of all, flush does not and cannot really support ACID, see DES 113. Second, the error situations one could think of are in no way expected, but refer to where unexpected, abnormal situation. In these situations, anyways the state of the overall system might be critical. We cannot foresee any possible error situations and we also cannot really pretend we can handle them correctly. The only advise for the user when an error in flush happens: If it might be a programming error, issue a bug. Otherwise, try closing and reopening the medium and redo the changes. In both cases, of course, due to DES 113, it could be that some changes have already been performed, which might leave the external medium in a corrupted state.
>
> **Nachteile:** No disadvantages known, as we hope there are really no cases where a retry would absolutely make sense

Now we have all credentials to implement writing in `flush()`:

1. Create the flush plan according to DES 113

2. **Phase 1 - Medium access phase:** Iterate all actions of the flush plan in order, but only handle the action types mentioned below in a specific way:

   - If action = `READ`: Call `getData` at the indicated offset to read n bytes. These bytes are written in the subsequent `WRITE` action. If an `EndOfMediumException` occurs, this is considered as impossible and an `IllegalStateException` is thrown. Store the read bytes to be used by the upcoming `WRITE` action. Set the action to done afterwards.

   - If action = `WRITE`: If the `WRITE` action contains bytes already, it as associated to an `INSERT` or `REPLACE`. In this case, directly write the contained bytes with direct access to the medium via `MediumAccessor`. If the action does not contain any bytes, the previous action must have been a `READ` reading exactly the same amount of bytes to write. If this is not the case, an `IllegalStateException` is thrown. Otherwise these previously read bytes are written with direct access to the medium via `MediumAccessor`. Set the action to done afterwards.

   - If action = `TRUNCATE`: Execute a truncation of the medium with direct access to the medium via `MediumAccessor`. Set the action to done afterwards.

3. **Phase 2 - Cache update phase:** Iterate all actions of the flush plan in order, but only handle the action types mentioned below in a specific way:

- If action = `INSERT`: First call `MediumChangeManager.undo` on the action. If there is an existing cache region containing the insertion offset, we have to split this region now at the insertion offset. The reason is: Otherwise the already cached portion of the cached region behind the insertion offset would not be shifted by the number of insertion bytes, and the cache would get corrupted. Then call `MediumOffset-Factory.updateReferences()` for the action. Finally add the insertion bytes to the cache. Here it must be noted that, as the cache add is done after `updateReferences()`, the insertion offset was increased already before, and we must decrease it again to add the cached bytes at the original insertion offset!

- If action = `REMOVE`: First call `MediumChangeManager.undo` on the action. Then remove the bytes in the removal region from the cache. Finally call `MediumOffsetFactory.updateReferences()` for the action.

- If action = `REPLACE`: First call `MediumChangeManager.undo` on the action. Then remove the bytes in the replaced region from the cache. Finally call `MediumOffsetFactory.updateReferences()` for the action, then add the replacement bytes to the cache.

> **DES 114:** `flush()` **is implemented according to the process defined above**
> `flush()` is implemented according to the process defined above
>
> **Begründung:** The flush plan must contain all operations explicitly, i.e. including those triggered by the user - `REPLACE`, `INSERT` and `REMOVE`, even if `READ` and `WRITE` would be sufficient for their implementation. The reason for that is that the actions of the user must explicitly be removed from the `MediumChangeManager` and their influence on `MediumOffset` instances behind must explicitly be executed. For this, you need the concrete types, `WRITE` is not sufficient.
> Throwing an `IllegalStateException` in case of end of medium encountered is necessary, as the creation of the flush plan must have considered the medium size. Thus, if it occurs, this is either a programming error in `createFlushPlan` or another process as changed the medium meanwhile.
> `undo()` is only executed for user operations, as only those are maintained in the internal data structures of `MediumChangeManager`, according to DES 114. Also, `undo()` must be executed first, otherwise `updateReferences()` changes offsets which would lead to a serious problem in a `TreeSet` as used in `MediumChangeManager` to find the correct reference with `contains`.
> The cache update is divided into two parts as mentioned in previous design decisions.
> The cache management is completely done within `MediumCache.addRegion()`, such that maximum size and consecutive regions can be optimized there.
>
> **Nachteile:** No disadvantages known

Implementation of `createFlushPlan`

The implementation of `createFlushPlan` is anything but trivial. The general algorithm is formally described in a separate paper (including examples), see [**?**].

Here, we only list some testcases that should be implemented to demonstrate the intended behaviour, see table 11.5. If we say

contains read/write-blocks from `<startOfs>` *to* `<endOfs>` `<backwards|forwards>`

in the table, we are referring to the following:

- The generated flush plan contains a sequence of `READ` and `WRITE` pairs starting at `start offset`, each `WRITE` following a `READ` with the same size.

- Each `READ` and each `WRITE` have a maximum size $s \leq m$, where m is the configured maximum read-write block size according to DES 114

- With $N := \text{endOfs} - \text{startOfs}$, there are exactly

$$\frac{N}{m} + N \bmod m$$

such pairs present

- They are either read "backward", i.e. chunk-wise starting at highest offset down to the lowest offset of the range, or "forward", i.e. chunk-wise starting at lowest offset up to the highest offset of the range

Also note that these tests do not contain any negative cases for scheduling actions that are overlapping in any invalid way. This must already be tested for the schedule operations of `MediumChangeManager`.

ID	Testcase	Variations	Expectation
CF0	No operation	-	The plan created is empty
CF1	Single `insert` n bytes at offset x	a. x is start, intermediate or end offset of the medium b. Bytes behind: None, or whole-numbered multiple of the maximum read-write block size m, or no whole-numbered multiple of m, or fewer bytes than m c. Insertion bytes: The same cases as for the bytes behind	• No read/write operations before insert offset • Bytes behind remain unchanged and get shifted by n towards higher offsets, such that medium length grows by n • Contains read/write-blocks from x to the end of medium backwards • The `insert` action follows after these actions in the plan

ID	Testcase	Variations	Expectation
CF2	Single `remove` n bytes at offset x	a. x is start, intermediate offset or $x+n$ is the end offset of the medium b. Bytes behind: None, or whole-numbered multiple of the maximum read-write block size m, or no whole-numbered multiple of m, or fewer bytes than m c. Extreme case: All bytes of the medium are removed	• No read/write operations before remove offset • Bytes behind remain unchanged and get shifted by n towards smaller offsets, such that medium length shrinks by n • Contains read/write-blocks from x to the end of medium forwards • The `remove` action follows after these actions in the plan • At the end there is a `truncate` operation

ID	Testcase	Variations	Expectation
CF3	Single `replace` of n bytes by r new bytes at offset x	a. x is start, intermediate offset or $x+n$ is the end offset of the medium b. Bytes behind: None, or whole-numbered multiple of the maximum read-write block size m, or no whole-numbered multiple of m, or fewer bytes than m c. Replacement bytes: Same cases as for bytes behind d. r smaller, equal to or bigger than n e. Extreme case: All bytes of the medium are replaced	• No read/write operations before replace offset • If $n > r$: Bytes behind remain unchanged and get shifted by $n-r$ towards smaller offsets, such that medium length shrinks by $n-r$, • If $r \geq n$: Bytes behind remain unchanged and get shifted by $r-n$ towards higher offsets, such that medium length grows by $r-n$, • Contains read/write-blocks from $x+n$ to the end of medium forwards (if $n > r$) or backwards (if $r > n$) • The `replace` action follows after these actions in the plan • If $n > r$: At the end there is a `truncate` operation

ID	Testcase	Variations	Expectation
CF4	Multiple `insert`s of in total n bytes	a. At same or different offsets b. Bytes in-between/behind: None, whole-numbered multiple of the maximum read-write block size m, or no whole-numbered multiple of m, or fewer bytes than m c. Bytes to insert: Same cases as for bytes behind	• No read/write operations before the first insert offset • Bytes behind last insertion remain unchanged and get shifted by n towards higher offsets, such that medium length grows by n • Bytes in between insertions: remain unchanged and are shifted to the back by the number of up-to-then inserted bytes • Each range between or behind inserts contains read/write-blocks from insertion offset x_i to the start of the next insertion (or end of medium) backwards • Each `insert` action follows after these block actions in the plan

ID	Testcase	Variations	Expectation
CF5	Multiple `remove`s of in total n bytes	a. All removes refer to consecutive regions or have gaps between b. Bytes in-between/behind: None, whole-numbered multiple of the maximum read-write block size m, or no whole-numbered multiple of m, or fewer bytes than m c. Extreme case: All bytes of the medium are removed	• No read/write operations before the first remove offset • Bytes behind last remove remain unchanged and get shifted by n towards smaller offsets, such that medium length shrinks by n • Bytes in between removes: remain unchanged and are shifted to the front by the number of up-to-then removed bytes • Each range between or behind removes contains read/write-blocks from offset $x_r + n_r$ up to the start of the next remove (or end of medium) forwards • Each `remove` action follows after these block actions in the plan • At the end there is a `truncate` operation

ID	Testcase	Variations	Expectation
CF6	Multiple `replace`s of in total n bytes by in total r new bytes	a. All replaces refer to consecutive regions or have gaps between b. Bytes in-between/behind: None, whole-numbered multiple of the maximum read-write block size m, or no whole-numbered multiple of m, or fewer bytes than m c. Replacement bytes: Same cases as for bytes behind d. r smaller, equal to or bigger than n e. Extreme case: All bytes of the medium are replaced	• No read/write operations before the first replace offset • If $n > r$: Bytes behind remain unchanged and get shifted by $n-r$ towards smaller offsets, such that medium length shrinks by $n-r$, • If $r \geq n$: Bytes behind remain unchanged and get shifted by $r-n$ towards higher offsets, such that medium length grows by $r-n$, • Bytes in between replaces: remain unchanged and are shifted to the front or back by the number of up-to-then replaced minus inserted bytes • Each range between or behind replaces contains read/write-blocks from offset $x_r + n_r$ up to the start of the next replace (or end of medium) forwards or backwards • Each `replace` action follows after these block actions in the plan • If $n > r$: At the end there is a `truncate` operation

ID	Testcase	Variations	Expectation
CF7	Multiple `remove`s and `insert`s	a. At same offsets, remove first then consecutive insert or at different offsets b. Mutually compensating or not c. First `remove`, then `insert`, or first `insert`, then `remove` - Note that remove and insert in any order at the same offset can be considered consective d. Extreme case: All bytes of the medium are removed, then new bytes inserted	• For read/write blocks and bytes between and behind: Same behaviour as for other test cases • For mutually compensating actions: Bytes behind the last action must not be read or written • The order of actions does not matter • For the extreme case: All bytes are actually "replaced" by the new inserted bytes

ID	Testcase	Variations	Expectation
CF8	Multiple `replace`s and `insert`s	a. At same offsets, replace first then consecutive insert or at different offsets b. Mutually compensating or not c. First `replace`, then `insert`, or first `insert`, then `replace` - Note that remove and insert in any order at the same offset can be considered consective d. r smaller, equal to or bigger than n e. Extreme case: All bytes of the medium are replaced, then new bytes inserted	• For read/write blocks and bytes between and behind: Same behaviour as for other test cases • For mutually compensating actions: Bytes behind the last action must not be read or written • The order of actions does not matter • For the extreme case: All bytes are actually "replaced" by the replacement bytes as well as the new inserted bytes

ID	Testcase	Variations	Expectation
CF9	Multiple `removes`s, `replace`s and `insert`s	a. At same offsets b. Mutually compensating or not c. In different orders d. Growing or shrinking the medium	• For read/write blocks and bytes between and behind: Same behaviour as for other test cases • For mutually compensating actions: Bytes behind the last action must not be read or written • The order of actions does not matter

Table 11.5.: Test cases for checking `createFlushPlan`

Configurating Medium Access

So far, we have identified several mechanisms the user can use to influence the behaviour of medium access: He can set the maximum cache size, he can disable caching alltogether, and he can also change the maximum read-write block size. But how? In DES 114, we explicitly said that for now, `jMeta` will not offer the possibility to change such parameters dynamically. Still we have to offer the user the corresponding API without exposing him to the internal details of the implementation.

We thus first define:

> **DES 115: The configuration of the medium access parameters is done per `Medium` instance**
>
> The configuration of `Media` is done per `Medium` instance. By doing this, all configuration parameters correlate to an `Medium`, have the same lifetime and scope. The setting of the parameters is done by passing them directly to the constructor of the media created by the user, with constructors setting the parameters to sensitive defaults.
>
> **Begründung:** The whole internal implementation of the most important classes, i.e. `MediumStore`, `MediumAccessor`, `MediumCache` and so on works on exactly one medium. The user can create `Medium` instances directly himself and configure them as needed, independent of other `Medium` instances. As these parameters must not change after creation of the medium, it is correct to pass them to the constructor and to not offer setters.
>
> **Nachteile:** No disadvantages known

Now the question arises: Which configuration parameters are needed in detail? We summarize them again in detail in table 11.6.

First of all, we exclude one potential parameter:

DES 116: **The maximum cache region size is not configurable by the user, but is automatically set to the maximum read-write block size** The user can only configure the maximum read-write block size, but not the maximum cache region size which is just set to the configured maximum read-write block size.

Begründung: For a usual user, it is not clear what the maximum cache region size really is and which size it should have; there is not much "tuning" potential in setting it to another value than the maximum read-write block size. By doing so, we have usually a one to one match betwen a read block of bytes and the medium region added to the cache. This is good performance-wise, as it does not require to e.g. read the content of a not-yet-cached medium region below maximum cache region size block-wise, in case the maximum read-write block size is smaller than the maximum cache region size. Instead, we just automatically set them to the same value, the user can only influence the maximum read-write block size. It is clearly documented to the user what it does. As additional plus, the configuration interface of a medium gets easier.

Nachteile: No disadvantages known

Medium	Parameter Name	Type	Default Value	Description
File, InputStream	`enableCaching`	boolean	`true`	Enables or disables caching for a medium according to DES 116. Setting this to `false` after creation of the `MediumStore` will clear the cache content directly. Implicitly set to `false` for `byte`-Array media according to DES 116
File, InputStream	`maxCacheSize`	long > 0	1 MB	Sets the maximum cache size according to DES 116. Changes to this parameter do not have any effect after the `MediumStore` was already created, so callers need to ensure to set this before creating the `MediumStore`.
File, byte-Array	`maxReadWriteBlockSize`	int > 0	8192	The maximum size of read-write-actions in bytes, that is triggered by `INSERT`s or `REMOVE`s during a `flush()`, see DES 116.

Table 11.6.: Configuration parameters of medium access

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