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Introduction

1.1 Scope
This document provides an overview of the APIs (C, Matlab) which can be used for evaluating and manipulating OpenCRG® data sets. It also contains a brief description of data formats used for storing OpenCRG® data.

1.2 The OpenCRG® C-API
The OpenCRG® C-API consists of a library and a set of tools. The latter also serves as a collection of examples for the usage of the library. All routines are provided in full source code.

The library can be used for reading, modifying and evaluating OpenCRG® data sets.

The API may be used free of charge in accordance with the licensing terms listed at the beginning of this document.

1.2.1 Platforms
The OpenCRG® C-API is written in ANSI-C and is supposed to be independent of hard- and software platforms. It was successfully tested in the following environments:

- Linux on PC
- MS Windows XP on PC
- Irix on sgi workstations

Big and little endian encoding of a given processor is detected automatically in the API.

1.2.2 Status
The OpenCRG® C-API is in release status. This implies that
- all available routines were tested on simplified examples
- performance optimization is in advanced state

1.3 The OpenCRG® Matlab Tools
The OpenCRG® Matlab Tools are provided on any system distributions including Matlab ( R14 ) or higher. No Toolbox or additional extensions are required. It is successfully tested in the following environments:

- Linux on PC ( incl. Matlab R 14 or higher )
- MS Windows XP on PC ( incl. Matlab R 14 or higher )

1.3.1 Status
The OpenCRG® Matlab Tools are in release status. This implies that
- all available routines were tested on simplified examples
1.4 Point of Contact

Further assistance concerning OpenCRG® and the C-API is provided via the OpenCRG® website www.opencrg.org via email opencrg@opencrg.org

and via the "classic style" of direct contact with human beings:

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2 OpenCRG®

2.1 Motivation
OpenCRG® is a complete open source project including a tool-suite for the creation, modification and evaluation of road surfaces, and an open file format specification CRG (curved regular grid). Its objective is to standardize a detailed road surface description and it may be used for applications like tire-, vibration- or driving-simulation.

2.2 The CRG Idea
A curved regular grid (CRG) represents road elevation data close to an arbitrary road centre line. The reference line may be complemented by slope or superelevation and is defined by consecutive heading angles.

The regular grid defines the elevation in proximity of the reference line. Columns are longitudinal cuts that are parallel to the reference line. Each row represent a lateral cut which is orthogonal to the reference line.

2.3 Reference Line Data Representation
The curved reference line is defined by a high precision start position and low precision heading angles. A potential drift due to path integration is prevented by redundant high precision end location of the reference line (Rauh@all 2008, s.6).

2.3.1 Reference Line Path Integration
High precision start-position, ending-position and consecutively heading angles allow to determine accurate reference line position data x(u), y(u). ‘Insufficient data precision leads to locally bad curvature representations achieved by simple 3-point-evaluations’ (Rauh@all 2008, s6).

Both OpenCRG® tools-suite APIs operate with a backward/forward integration to determine reference line position data. The given high precision start and end positions are compared to the integration results to determine whether the input describes a smooth track.
3 OpenCRG® Data Files

3.1 The Basics

OpenCRG® data files consist of various sections which are each enclosed by a line containing the corresponding keyword and a line with a terminating character set. Data files may contain road data in user-readable (i.e. ASCII) format or as binary stream (recommended for large data sets).

The keywords distinguishing the sections start with the $ character followed by the keyword itself. Keywords must be placed at the beginning of a new line and must not be followed by any data but some sort of comment. A section is terminated with a simple $ character at the beginning of a new line.

The possible sections within an OpenCRG® data file are shown in the following figure:

- **$CT:** mandatory comment about file’s contents
- **$ROAD_CRG:** information about centerline; mandatory if file contains Data section,
- **$KD_Definition:** definition of individual channel parameters; mandatory if file contains Data section
- **$ROAD_CRG_OPTS:** evaluation options
- **$ROAD_CRG_MODS:** data set modifiers
- **$ROAD_CRG_FILE:** references to other data files
- **Data** the actual OpenCRG® data

The sequence of the sections within an OpenCRG® file is irrelevant, except for the Comment block which has to be the first section within the file and the Data block which, if present, has to be the last. However, it is recommended to use the above scheme for the creation of new files (for user readability).

An OpenCRG® file may contain reference directives pointing to other files. This is usually the case when a control file is used for defining options and modifiers (see below) and the actual data is contained in a separate file. A typical application for referring to other files is shown in the following figure.
3.2 Comments

Comments may be defined in two ways:
- the * character at the beginning of a line makes the entire line a comment
- the ! character within a line will cause all following characters to be treated as comment (until the end of the line)

3.3 The Sections in Detail

3.3.1 Header Information

Each data file MUST start with a comment block (header information) giving some information about the file's contents (preferably) etc.

The keyword is: $CT

Example:

```
$CT                                                 ! comment text block
CRG file example for road surface description (width: 3m, length: 22m)
with sloped reference line and grid of (0.25m...1.0m) x 1.0m
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More Information on OpenCRG open file formats and tools can be found at
   http://www.opencrg.org
$!
```

Note that in the example, the header information block is terminated by the $ character in the bottom line. The ! character labels all following characters to be treated as comment and thus to be ignored by the data loader. They have just been added for user-readability of the data file.
3.3.2 Road Parameters

The road parameter section defines various parameters for the reference line and the overall configuration of the longitudinal sections. The minimum content that must be defined is the distance between lateral cross sections (REFERENCE_LINE_INCREMENT). All other parameters are optional. A complete road parameter list including MATLAB-API equivalents and descriptions is listed at './matlab/lib/crg_intro.m' (see 'head' section).

The keyword is: $ROAD_CRG$

Example 1:

```
$ROAD_CRG                                          ! crg road parameters
REFERENCE_LINE_START_U   = 0.0
REFERENCE_LINE_START_X   = 0.0
REFERENCE_LINE_START_Y   = 0.0
REFERENCE_LINE_START_PHI = 0.0
REFERENCE_LINE_END_U     = 22.0  !mandatory content
REFERENCE_LINE_END_PHI   = 0.0
REFERENCE_LINE_INCREMENT = 1.0
LONG_SECTION_V_RIGHT     =-1.50         ! with explicit definition below
LONG_SECTION_V_LEFT      = 1.50         ! with explicit definition below
$!**********************************************************************
```

Example 2: To avoid potential problems in reference line reconstruction, it is recommended to add start and end positions in the header:

```
$CRG_ROAD
...                     
REFERENCE_LINE_START_X = 0.0
REFERENCE_LINE_START_Y = 0.0
REFERENCE_LINE_END_X   = 220.0
REFERENCE_LINE_END_Y   = 324.0
$
```

Example 3: If GPS (WGS84) co-ordinates of the start and end position are available, these should be provided additionally in the road parameter section (not yet supported by C-API):

```
$CRG_ROAD
...                     
reference_line_start_lon =  9.12345
reference_line_start_lat =  4.98765
reference_line_end_lon   =  9.22345
reference_line_end_lat   =  4.88765
$
```
3.3.3 Data Definition

The data definition block defines the data format (ASCII / binary) and the sequence of data which is to be expected in the trailing data block. Each definition starts with a D: identifier. Reference line and grid data may be defined within the data definition block (again, depending on the contents of the actual data block). Further details can be retrieved from the Matlab routines available for writing OpenCRG® data.

The keyword is: $KD_Definition

Example 1: sloped dataset with seven longitudinal sections

```
$KD_DEFINITION ! data definition block
#:LRFI ! one of the men readable IPLOS formats
D:reference line slope,m/m                   ! longitudinal slope
D:long section at v = -1.500,m           ! 1.50m right of reference line
D:long section at v = -1.250,m           ! 1.25m right of reference line
D:long section at v = -1.000,m           ! 1.00m right of reference line
D:long section at v =  0.000,m           ! on reference line
D:long section at v =  1.000,m           ! 1.00m left of reference line
D:long section at v =  1.250,m           ! 1.25m left of reference line
D:long section at v =  1.500,m           ! 1.50m left of reference line
$!**********************************************************************
```

Example 2: curved data set with heading angle defined as first item of each data entry

```
$KD_DEFINITION
#:LDFI
D:reference line phi,rad       ! heading angle -pi <= phi <= +pi
D:long section at v = -1.500,m ! longitudinal cuts with position
D:long section at v = -1.250,m
D:long section at v = -1.000,m
...
$$$$$$$
```

Example 3: longitudinal sections in fixed lateral spacing (lateral spacing 0.1m, surface width 3m); this example also shows the interaction between the blocks $CRG_ROAD and $KD_DEFINITION

```
$CRG_ROAD ! minimal header
REFERENCE_LINE_INCREMENT = 0.01 ! 1cm spacing of lateral cuts
LONG SECTION_V_RIGHT     = -1.50 ! right surface border
LONG SECTION_V_LEFT      =  1.50 ! left surface border
LONG SECTION_V_INCREMENT = 0.10 ! 10cm spacing of longitudinal cuts
$
$KD_DEFINITION
#:LDFI
D:reference line phi,rad       ! heading angle -pi <= phi <= +pi
D:long section 1,m             ! 1.5m right of reference line
D:long section 2,m             ! 1.4m right of reference line
...
D:long section 31,m            ! 1.5m left of reference line
```

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3.3.4 **Modifiers and Options**

As shown in the figure at the beginning of this chapter, OpenCRG® data files may also contain information about data evaluation options and data set modifiers. Both may, alternatively, be defined in run-time using the APIs.

The details of options and modifiers are described in the chapters below. Here, it shall only be stated that the keywords are:

Options: \$ROAD\_CRG\_OPTS
Modifiers: \$ROAD\_CRG\_MODS

Example:

```bash
\$ROAD\_CRG\_OPTS                          ! crg runtime evaluation options
*  
* BORDER\_MODE\_U = 0                   ! return NaN
* BORDER\_MODE\_U = 1                   ! set zero
* BORDER\_MODE\_U = 2                   ! keep last (default)
* BORDER\_MODE\_U = 3                   ! repeat
* BORDER\_OFFSET\_U = 1.0               ! z offset beyond border (default: 0)
*  
* BORDER\_MODE\_V = 0                   ! return NaN
* BORDER\_MODE\_V = 1                   ! set zero
* BORDER\_MODE\_V = 2                   ! keep last (default)
* BORDER\_MODE\_V = 3                   ! repeat
  BORDER\_OFFSET\_V = 1.0               ! z offset beyond border (default: 0)
$!**********************************************************************
```

**NOTE:** In the API routines, default modifiers and options are defined. Options provided in an individual data file may alter the default values of the respective options. Defining a modifier block in the data file will trigger the removal of ALL default modifiers. The user-defined modifiers will be set according to the information provided in the data file. If the user provides an empty "$ROAD\_CRG\_MODS" block, then no modifiers will remain at all (for default modifiers see also 4.2.7.1)

3.3.5 **File Reference**

OpenCRG® files may contain references to other files, typically containing the actual data. In the "master" file, conventions for modifiers and options will typically be defined. File references may contain absolute or relative paths and environment variables.

The keyword is:  \$ROAD\_CRG\_FILE

Example:

```bash
\$ROAD\_CRG\_FILE                                      ! crg file reference
  
  * The file name may be split to multiple lines, which must not contain
  * leading/trailing blanks, *, or ! to be considered as part of the name.
  * Each line length must not exceed 72 characters.
  * If a relative path is given, it is evaluated relative to the current
  * directory of the reader process.
  * If the first character is a $, subsequent characters will be replaced
  * by the contents of the equivalent environment variable.
  *  
  * > /home/name/crg-files/handmade_straight.crg  ! absolute path
  *  
  * > /home/name/crg-files/hand                  ! absolute path
  * > made_straight.crg                           ! split in 2 lines
  *  
  * > $crgpath/handmade_straight.crg              ! replace $crgpath by
  * >                                             ! it's envvar contents
  *  
  * > ./hand                                       ! look in current dir
  * made_straight_opts.crg                        ! look in current dir
```

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3.3.6 Road Data

The road data section MUST ALWAYS be the last section of an OpenCRG® data file. It contains the actual road data (typically: elevation). Its formatting depends on the data format defined in the Data Definition section (see above). Since OpenCRG® files will typically be written using the Matlab routines, a further discussion of the various data formats is omitted (for the moment).

3.4 Sample Files

OpenCRG® sample data files are located in the directories

```
OpenCRG/crg-txt
OpenCRG/crg-bin
```

A distinction is made between human-readable text files and binary data files. Each type is located in its respective sub-directory.

The following files are available:

```
|----crg-bin
|   |----belgian_road.crg...binary data set for tests complex tests
|   |----country_road.crg.........a larger stretch of binary test data (*
|----crg-txt
|   |----fileref.crg...............user-readable data set referring CRG file
|   |----fileref_mods.crg..........user-readable data set referring CRG file w. modifier
|   |----fileref_opts.crg...........user-readable data set referring CRG file w. options
|   |----handmade_arc.crg...........user-readable data set for a -180deg arc
|   |----handmade_banked.crg........user-readable data set for banked road data
|   |----handmade_circle.crg........user-readable data set for closed refline
|   |----handmade_curved.crg........user-readable data set for curved refline
|   |----handmade_curved_banked_sloped.crg...." data set for curved refline w. opts/mod
|   |----handmade_curved_minimalist.crg........" data set for minimalist curved refline
|   |----handmade_platform.crg.......user-readable data set for constantly elevated road
|   |----handmade_sloped.crg.........user-readable data set for sloped data set
|   |----handmade_sloped_opt.crg.......user-readable data set for sloped data set w. options
|   |----handmade_straight.crg........user-readable data set for straight refline
|   |----handmade_straight_double.crg..user-readable data set for st. refline in double prec.
|   |----handmade_straight_minimalist.crg........" data set for minimalist straight refline
|   |----handmade_vtest.crg............user-readable data set for tests relating to v-options
|---testOptionBorderMode.crg.....master file including data file and setting options
```

* Available as additional sample at www.opencrg.org/download.htm

Other files may be added to the data directories without further notice or explicit description in this documentation.
4 The OpenCRG® C-API

4.1 Getting Started

4.1.1 Downloading the Software Package
The latest stable version of the OpenCRG® C-API may be retrieved via the website

    www.opencrg.org

Go to the Downloads area and look for the section Packages and Tools. There, you will find a package containing the C-API, MATLAB routines, documentation and sample files. Download this package and unpack it into a dedicated directory on your machine.

The C-API is located in the sub-directory

    OpenCRG/c-api

The latest developer version may be retrieved via the OpenCRG® project managing and issue tracking-system. You can reach this system by going to

    http://tracking.vires.com (registration required)

4.1.2 Release Notes
The release notes are part of the software package and will not be transferred to this document. Please look for the “readme.txt” files in the root directory of the OpenCRG package and in the API’s sub-directory.
4.1.3 Contents of the Package

The OpenCRG® C-API is delivered as a zipped package which, after unpacking, provides the following file structure (for additional / updated contents, see the readme.txt file):

|----baselib.................OpenCRG basic library - the core of the toolset |
|   |----lib....................location of the compiled OpenCRG library |
|   |----inc.................include files providing the interface to the library |
|   |----makefile............sample makefile for users preferring the make mechanism |
|   |----obj....................target directory for sources compiled with the make mechanism |
|   |----src..................the library’s sources |
|   |----compileScript.sh.......script for the compilation of all demos and tools, |
|   |   based on simple compiler calls; this is an alternative to |
|   |   using the make mechanism; all files of the base library are |
|   |   also compiled with this script, so there is no need for a |
|   |   separate compilation of the library files. |
|----demo....................demo sources showing the usage of the basic library |
|   |----Simple.............a really simple application covering all basics of the API, |
|   |   runs with fix data sample “handmade_straight.crg” |
|   |----EvalOptions.........a set of routines demonstrating the usage of various options |
|   |----EvalXYnUV..........a set of routines for the evaluation of OpenCRG reference lines |
|   |----EvalZ.............an advanced example for the evaluation of OpenCRG data |
|   |----Reader.............a sample application for a CRG file reader |
|   |----bin |
|   |   |----crgSimple....executable of the very simple example |
|   |   |----crgEvalxyuv..executable of the reference line evaluator |
|   |   |----crgReader....executable of the sample reader |
|   |   |----crgEvalz....executable of the complex z data evaluator |
|   |   |----crgEvalOpts..executable of the option usage example |
|   |   |----makefile............makefile for all demos (alternative to "compileScript.sh") |
|----makefile |
|----readme.txt |
|----test |
|   |----PerfTest.............test tool for evaluating the performance of the library |
|   |----bin |
|   |   |----testModifiers.sh...script for performing a series of tests using the |
|   |   |   modifier mechanisms; requires gnuplot |
|   |   |----testOptions.sh.....script for performing a series of tests using the |
|   |   |   evaluation option mechanisms; requires gnuplot |
|   |   |----crgPerfTest........performance test tool; may not run on all platforms |
|   |   |----makefile............makefile for all tests (alternative to "compileScript.sh") |

4.1.4 Compiling the Package

4.1.4.1 Method A – makefiles

On machines with gcc and standard make environment, just type

make

in the root directory. This should result in a series of executable files in the directories

demo/bin/
test/bin/

In addition, a library containing all object files of the baselib/ sources is created in

baselib/lib
4.1.4.2 Method B – script

On machines having trouble with the provided makefiles, either adapt those files or use the very basic fallback solution which is a compile script. The script "compileScript.sh" is located in the root directory

    OpenCRG/c-api/

Open the script, set the compiler variable "COMP" to the name of your compiler, re-save the script and execute it. The results should - again - be found in

    demo/bin/
    test/bin/

In contrast to the makefile mechanism, no library is explicitly created from the baselib/ files.

4.1.4.3 Method C – command line

If you don't like makefiles and our scripts, you may just write your own simple compile instruction at command line level.

For this purpose, please note the following hints:

In order to compile a demo, set your include file search path to

    baselib/inc

Always compile in combination with all .c-files in

    baselib/src

Example: For the compilation of EvalXYnUV, use:

    cc -lm -o EvalXYnUV -I baselib/inc demo/EvalXYnUV/src/main.c baselib/src/*.c

4.1.5 Basic Tests

On machines providing a shell environment and gnuplot (e.g. Linux systems), a series of very brief tests can be run. These are also used for acceptance tests of the C-API and have generated the figures in this document showing the various options and modifiers.

In order to run all tests for evaluation options, use the script

    testOptions.sh

In order to run all tests for data set modifiers, use the script

    testModifiers.sh
4.2 The Base Library

4.2.1 Overview

As mentioned above, the base library contains a large set of routines for
- reading
- modifying
- evaluating

OpenCRG® data. If you’re looking for tools for creating data sets, please refer to the Matlab routines also available via the OpenCRG® website.

The base library is contained completely in the subdirectory

baselib/

of the OpenCRG® software package. It has the following structure:

inc/ all include files
obj/ objects and library resulting from compilation
src/ all source files
makefile the makefile for compiling the library

Once compiled with the provided makefiles, the library is stored as archive in the directory

lib/

below the OpenCRG/ root directory.

4.2.2 Include Files

The API comes with two include files

baselib/inc/crgBaseLib.h
baselib/inc/crgBaseLibPrivate.h

The first include file will typically be used when writing own applications featuring the OpenCRG® library. The second include file is used internally by the library’s components and, therefore, can be ignored in most cases. It includes itself the first library, so when working with the “private” header, you don’t have to include the “public” header explicitly.

4.2.3 Source Files

The library is composed of the following source files which are located in baselib/src:

crgMgr.c overall data management
crgMsg.c message / data log handling
crgStatistics.c calculation of data set statistics
crgContactPoint.c contact point management
crgEvalxy2uv.c routines for evaluating x/y -> u/v
crgEvalu2xy.c routines for evaluating u/v -> x/y
crgEvalz.c routines for evaluating x/y -> z, u/v -> z
crgEvalpk.c routines for evaluating x/y -> phi / kappa, u/v -> phi / kappa
crgLoader.c data file decoder and data loader
crgOptionMgmt.c management of options and modifiers
collection of routines which might be subject to portability issues (e.g. when integrating the library within FORTRAN)

The interface to the methods in all source files is given in the include files listed in the previous chapter. The actual location of a method within the set of source files is irrelevant to the standard use of the library.

4.2.4 Working with Data Files

4.2.4.1 Simple Use Case

There are many operations that may be applied to OpenCRG® data sets. However, the simple way of using OpenCRG® data files is split into just three stages:

1. load the file
2. create a contact point
3. call the evaluation methods

This use case is shown in a programming example which is located at

demo/Simple/

4.2.4.2 Data Sets and Contact Points

This document and the entire C-API use two terms which shall be explained here:

- **Data Set**: a data set is the instance of data read from an OpenCRG® file into memory. It is identified by a unique integer ID which is returned by the data loader method.

- **Contact Point**: a contact point is a "tool" to query data of a given data set. The user must instantiate at least one contact point per data set in order to be able to query its contents. Contact points are identified with unique integer IDs which are returned by the contact point creation method. The number of contact points per data set is not limited.

4.2.4.3 Multi-Thread Applications

To parallelize C-API evaluation calls, contact points MUST NOT be shared between threads. Doing this will destroy history and other data stored within the contact point "object".

4.2.4.4 Modifiers and Options

In simple cases, data sets will be read from file and evaluations may take place immediately. However, the user may want to vary the way a specific data set is evaluated without having to modify the original data (i.e. the data file) itself.

For this purpose, modifiers and options have been introduced.

- **Modifiers**: modify the copy of OpenCRG® data which is stored in memory and, therefore, provide the modified data for all subsequent evaluation requests.

- **Options**: influence the way a specific query is performed without modifying any of the data stored in memory.

In the data files, modifiers are found in the section $CRG_MODS and options are found in $CRG_OPTS. The API provides discrete calls for setting modifiers directly and for applying them and the ones defined in the data file to the data set. For reasons of enhanced user control, modifiers defined in a
data file are NOT applied automatically to the data set. It is the user's responsibility to apply them explicitly (see below).

The API also provides calls for setting options on a contact point level. When setting an option, its data type is taken into account, resulting in different methods for double and integer modifiers/options.

The set of available modifiers and options is defined as symbolic constants in the include file `crgBaseLib.h`.

**Modifiers** are set on a data set level by means of the routines

```
crgDataSetModifierSetInt( dataset, ... )
crgDataSetModifierSetDouble( dataset, ... )
```

After complete definition of all modifiers, they must be applied explicitly to the data set using the method

```
crgDataSetModifiersApply( dataset )
```

**NOTE:** This routine must also be called after reading the modifiers from a CRG file. Only defining the section `$ROAD_CRG_MODS` in a CRG files will NOT trigger the application of the modifiers to the data set.

In contrast to modifiers, **options** are applied implicitly each time an evaluation is performed. Therefore, they only have to be defined on a contact point level using the methods

```
crgContactPointOptionSetInt( contactPoint )
crgContactPointOptionSetDouble( contactPoint )
```

### 4.2.4.5 Sequence of Actions

The following figure gives an overview of the sequence of actions that may be performed when working with OpenCRG® data files.

- first, the user loads a file; the file may already contain definitions for evaluation options and data set modifiers.
- upon reading the file, a data set with a unique ID (returned by the loader method) is created where actual OpenCRG® data is stored as well as modifiers and options defined within the file.
• after reading the file, the modifiers of the data set may be replaced, deleted, extended by means of API calls referring to the data set.
• in order to evaluate data of the data set, the user needs to create a so-called “contact point”; this contact point is dedicated to a given data set; the library creates and returns a unique ID for each contact point
• the contact point inherits all evaluation options from the respective data set
• the user may specify further evaluation options, modify existing ones or delete all evaluation options inherited from the data set
• finally, evaluation of data may begin

4.2.5 Evaluating Data

Once a data set is loaded and a contact point is created, data can be evaluated in various ways (full prototypes of the referenced methods are in crgBaseLib.h)

• compute the x/y position of a given u/v position
  
  crgEvaluv2xy( int cpId, double u, double v, double* x, double* y )

• compute the u/v position of a given x/y position
  
  crgEvalxy2uv( int cpId, double x, double y, double* u, double* v )

• compute the z value at a given u/v position
  
  crgEvaluv2z( int cpId, double u, double v, double* z )

• compute the z value at a given x/y position
  
  crgEvalxy2z( int cpId, double x, double y, double* z )

• compute heading angle and curvature at a given u/v position
  
  crgEvaluv2pk( int cpId, double u, double v, double* phi, double* curv )

4.2.6 Message Printing

The API provides a series of methods for controlling verbosity of the library. Also, the user may use these methods to provide / control own messages which are to be printed to shell output (here: stderr).

The system knows the following message levels (in increasing order) which are controlled by symbolic constants in crgBaseLib.h

  dCrgMsgLevelNone
  dCrgMsgLevelFatal
  dCrgMsgLevelWarn
  dCrgMsgLevelNotice
  dCrgMsgLevelInfo
  dCrgMsgLevelDebug

The current message level is set by

  crgMsgSetLevel( int level );

A message to be printed at or below a certain level is defined in standard printf() syntax via
crgMsgPrint( int level, const char *format, ...);

If a user wants to perform custom message handling, a callback may be defined which is invoked instead of the internal print routines. The syntax for setting the callback is: printf() syntax via

    crgMsgSetCallback( int (*func)( int level, char* message ) );

An example for custom message handling is given in the demo/EvalOptions/src/main.c. Look for the method myMsgHandler(...).

4.2.7 Modifiers

As mentioned above, the OpenCRG® data set stored in memory may be globally modified by means of so-called “modifiers”.

The C-API provides a series of methods for defining, querying, and printing modifiers of a data set. These are described in further detail in the header file crgBaseLib.h and are following the naming pattern

    crgDataSetModifierxxx( dataSetId, ... );

The following tables and figures give an overview of all applicable modifiers with their respective definitions within OpenCRG® data files and with their addressing from the API. All examples have been computed using the test tool located in Tools/EvalOptions via the script testModifiers.sh in Tools/bin.

4.2.7.1 Default Modifiers

The C-API (similar to the Matlab API) defines a set of default modifiers which are applied to the data set if no other modifiers have been defined in the OpenCRG® data file. However, as pointed out above, application of the modifiers must explicitly be triggered by calling the routine

    crgDataSetModifiersApply( dataset )

The default modifiers may be altered and extended in the following ways:

- Block "$ROAD_CRG_MODS" in the OpenCRG® data file
  Upon first occurrence of this block ALL default modifiers will be deleted (i.e. even the ones you might have wished to keep). These are replaced with the modifiers defined in the corresponding data block. The removal of all modifiers by means of an OpenCRG® data file is achieved by providing an empty block "$ROAD_CRG_MODS"

- Calls to C-API
  By explicitly setting / removing modifiers via the C-API routines

    crgDataSetModifierSetInt( dataset, ... )
    crgDataSetModifierSetDouble( dataset, ... )
    crgDataSetModifierRemoveAll( dataset )
    crgDataSetModifierSetDefault( dataset )

  the user may further customize the list of applicable modifiers

- Combination of both methods
The default modifiers are (details see below):

<table>
<thead>
<tr>
<th>symbolic constant</th>
<th>C-API data type</th>
<th>value</th>
<th>data file name</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>dCrgModRefPointUFrac</td>
<td>double</td>
<td>0.0</td>
<td>REFPOINT_U_FRACTION</td>
<td>0.0</td>
</tr>
<tr>
<td>dCrgModRefPointUOffset</td>
<td>double</td>
<td>0.0</td>
<td>REFPOINT_U_OFFSET</td>
<td>0.0</td>
</tr>
<tr>
<td>dCrgModRefPointVFrac</td>
<td>double</td>
<td>0.0</td>
<td>REFPOINT_V_FRACTION</td>
<td>0.0</td>
</tr>
<tr>
<td>dCrgModRefPointVOffset</td>
<td>double</td>
<td>0.0</td>
<td>REFPOINT_V_OFFSET</td>
<td>0.0</td>
</tr>
<tr>
<td>dCrgModRefPointX</td>
<td>double</td>
<td>0.0</td>
<td>REFPOINT_X</td>
<td>0.0</td>
</tr>
<tr>
<td>dCrgModRefPointY</td>
<td>double</td>
<td>0.0</td>
<td>REFPOINT_Y</td>
<td>0.0</td>
</tr>
<tr>
<td>dCrgModRefPointZ</td>
<td>double</td>
<td>0.0</td>
<td>REFPOINT_Z</td>
<td>0.0</td>
</tr>
<tr>
<td>dCrgModRefPointPhi</td>
<td>double</td>
<td>0.0</td>
<td>REFPOINT_PHI</td>
<td>0.0</td>
</tr>
<tr>
<td>dCrgModGridNaNMode</td>
<td>int</td>
<td>dCrgGridNaNKeepLast</td>
<td>GRID_NAN_MODE</td>
<td>2</td>
</tr>
</tbody>
</table>
4.2.7.2 Transforming Data by Reference Point

The data set may be “re-located” by defining a reference point in the u/v grid and an inertial target position and orientation.

The reference point may be defined using explicit u/v values:

<table>
<thead>
<tr>
<th>C-API</th>
<th>symbolic constant</th>
<th>data type</th>
<th>values</th>
<th>data file, section SCRG_MODS name</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>dCrgModRefPointU</td>
<td>double</td>
<td>REFPOINT_U</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dCrgModRefPointV</td>
<td>double</td>
<td>REFPOINT_V</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It may also be defined using relative u/v values and explicit offsets (in [m]) from these relative positions (or by mixing the former position mode with the current one):

<table>
<thead>
<tr>
<th>C-API</th>
<th>symbolic constant</th>
<th>data type</th>
<th>values</th>
<th>name</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>dCrgModRefPointUFrac</td>
<td>double</td>
<td>0.0..1.0</td>
<td>REFPOINT_U_FRACTION</td>
<td>0.0..1.0</td>
<td></td>
</tr>
<tr>
<td>dCrgModRefPointUOffset</td>
<td>double</td>
<td>REFPOINT_U_OFFSET</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dCrgModRefPointVFrac</td>
<td>double</td>
<td>0.0..1.0</td>
<td>REFPOINT_V_FRACTION</td>
<td>0.0..1.0</td>
<td></td>
</tr>
<tr>
<td>dCrgModRefPointVOffset</td>
<td>double</td>
<td>REFPOINT_V_OFFSET</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The target position of the data set must be defined in inertial co-ordinates and with absolute heading angle.

<table>
<thead>
<tr>
<th>C-API</th>
<th>symbolic constant</th>
<th>data type</th>
<th>values</th>
<th>name</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>dCrgModRefPointX</td>
<td>double</td>
<td>REFPOINT_X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dCrgModRefPointY</td>
<td>double</td>
<td>REFPOINT_Y</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dCrgModRefPointZ</td>
<td>double</td>
<td>REFPOINT_Z</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dCrgModRefPointPhi</td>
<td>double</td>
<td>REFPOINT_PHI</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Example 1:

modifier: refpoint u=5.0, v=1.5 to position x=100.0, y=200.0, z=10.0
file: handmade_straight.crg

original data set

modified data set
4.2.7.3 Transforming Data by Offset Position

Instead of defining a reference point and its target location, the data set may be shifted and rotated using translation and angle offsets which are applied to the origin of the data set's reference line. At first, the rotation is applied before the reference line translation. If not defined, the default rotation center will be the starting position (x,y).

<table>
<thead>
<tr>
<th>symbolic constant</th>
<th>data type</th>
<th>values</th>
<th>name</th>
<th>data file</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>dCrgModRefLineRotCenterX</td>
<td>double</td>
<td></td>
<td>REFLINE_ROTCENTER_X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dCrgModRefLineRotCenterY</td>
<td>double</td>
<td></td>
<td>REFLINE_ROTCENTER_Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dCrgModRefLineOffsetPhi</td>
<td>double</td>
<td></td>
<td>REFLINE_OFFSET_PHI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dCrgModRefLineOffsetX</td>
<td>double</td>
<td></td>
<td>REFLINE_OFFSET_X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dCrgModRefLineOffsetY</td>
<td>double</td>
<td></td>
<td>REFLINE_OFFSET_Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dCrgModRefLineOffsetZ</td>
<td>double</td>
<td></td>
<td>REFLINE_OFFSET_Z</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Example 1:

**modifier:** translation of reference line by x=100.0, y=200.0, z=10.0  
**file:** handmade_straight.crg

Example 2:

**modifier:** translation of reference line by x=100.0, y=100.0, z=100.0  
rotation by 1.57 (rad)  
**file:** handmade_straight.crg
4.2.7.4 Scaling of Elevation Data

Various properties influencing the elevation of the data set may be scaled. These are listed in the following table. A scale value of 0 will lead to ignoring the respective property.

<table>
<thead>
<tr>
<th>C-API</th>
<th>data type</th>
<th>values</th>
<th>name</th>
<th>data file</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>dCrgModScaleZ</td>
<td>double</td>
<td>SCALE_Z</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dCrgModScaleSlope</td>
<td>double</td>
<td>SCALE_SLOPE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dCrgModScaleBank</td>
<td>double</td>
<td>SCALE_BANK</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Example 1:

modifier: z scale 10.0  
file: handmade_straight.crg

Example 2:

modifier: slope scale 10.0  
file: handmade_sloped.crg
Example 3:

**modifier:** bank scale 10.0

**file:** handmade_banked.crg

---

**original data set**

![original data set](image1)

**modified data set**

![modified data set](image2)

---

Refer to protection notice DIN ISO 16016. Use of this data is subject to the OpenCRG public license policy
4.2.7.5 Scaling of Data Set Extents

The length and width of the data set may be scaled. Only values greater than zero are valid.

<table>
<thead>
<tr>
<th>C-API</th>
<th>symbolic constant</th>
<th>data type</th>
<th>values</th>
<th>name</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>dCrgModScaleLength</td>
<td>double</td>
<td>[0.0..]</td>
<td>SCALE_LENGTH</td>
<td>[0.0..]</td>
</tr>
<tr>
<td></td>
<td>dCrgModScaleWidth</td>
<td>double</td>
<td>[0.0..]</td>
<td>SCALE_WIDTH</td>
<td>[0.0..]</td>
</tr>
</tbody>
</table>

**Example 1:**
- **modifier:** length scale 10.0
- **file:** handmade_sloped.crg

**Example 2:**
- **modifier:** width scale 2.0
- **file:** handmade_banked.crg

Refer to protection notice DIN ISO 16016. Use of this data is subject to the OpenCRG public license policy.
4.2.7.6 Scaling of Curvature

The reference line curvature may be scaled resulting in a modified end point. Scaling by a value of zero will result in a straight reference line.

<table>
<thead>
<tr>
<th>C-API data file symbol constant values</th>
<th>data file values</th>
</tr>
</thead>
<tbody>
<tr>
<td>dCrgModScaleCurvature</td>
<td>double SCALE_CURVATURE</td>
</tr>
</tbody>
</table>

**Example 1:**
- **modifier:** curvature scale 0.50
- **file:** handmade_arc.crg

**Example 2:**
- **modifier:** curvature scale 0.00
- **file:** handmade_arc.crg

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4.2.7.7 NaN handling in v Direction

When preparing the data set for queries, the v border values are checked for NaNs. The mode of treating these values can be set by the user.

<table>
<thead>
<tr>
<th>symbolic constant</th>
<th>C-API data type</th>
<th>values</th>
<th>name</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>dCrgModGridNaNMode</td>
<td>int</td>
<td>dCrgGridNaNKeep</td>
<td>GRID_NAN_MODE</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>dCrgGridNaNSetZero</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>dCrgGridNaNKeepLast</td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

When using mode dCrgGridNaNKeep/0, the option dCrgCpOptionBorderModeV/BORDER_MODE_V must also be set to dCrgBorderModeNone/0.

Unless NaN is being kept, an explicit offset may be applied to former NaN values in the grid.

<table>
<thead>
<tr>
<th>symbolic constant</th>
<th>C-API data type</th>
<th>values</th>
<th>name</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>dCrgModGridNaNOffset</td>
<td>double</td>
<td></td>
<td>GRID_NAN_OFFSET</td>
<td></td>
</tr>
</tbody>
</table>
4.2.8 Options

As mentioned above, the evaluation methods per contact point may be influenced by so-called "options". This means that options are applied per evaluation, not on a global level.

The C-API provides a series of methods for defining, querying, and printing options of a contact point. These are described in further detail in the header file `crgBaseLib.h` and are following the naming pattern

```
crgContactPointOptionxxx( contactPointId, ... );
```

The following tables and figures give an overview of all applicable options with their respective definitions within OpenCRG® data files and with their addressing from the API. All examples have been computed using the test tool located in `Tools/EvalOptions` via the script `testOptions.sh` in `Tools/bin`.

4.2.8.1 Border Modes in u and v Directions

The border modes influence (per direction) the z value returned when the original definition area (i.e. within the min. and max. u- and v-co-ordinates) is exceeded by a query.

For each border, the following behaviors may be defined:

- return NaN/error, i.e. refuse the query
- set the value to zero
- keep the last value
- repeat the core area data
- reflect the core area data

In order to mark the border itself, a z-offset may be applied when the border is crossed in either direction. The interface for defining the respective modes is as follows (default values are highlighted):

<table>
<thead>
<tr>
<th>symbolic constant</th>
<th>C-API data type</th>
<th>values</th>
<th>data file name</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>dCrgCpOptionBorderModeU</td>
<td>int</td>
<td>dCrgBorderModeNone</td>
<td>BORDER_MODE_U</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>dCrgBorderModeExZero</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>dCrgBorderModeExKeep</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>dCrgBorderModeRepeat</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>dCrgBorderModeReflect</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>dCrgCpOptionBorderModeV</td>
<td>int</td>
<td>dCrgBorderModeNone</td>
<td>BORDER_MODE_V</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>dCrgBorderModeExZero</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>dCrgBorderModeExKeep</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>dCrgBorderModeRepeat</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>dCrgBorderModeReflect</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>dCrgCpOptionBorderOffsetU</td>
<td>double</td>
<td></td>
<td>BORDER_OFFSET_U</td>
<td></td>
</tr>
<tr>
<td>dCrgCpOptionBorderOffsetV</td>
<td>double</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Example 1:

options: border mode U = dCrgBorderModeNone
file:    handmade_sloped.crg

default settings

Example 2:

options: border mode U = dCrgBorderModeExZero
          border mode V = dCrgBorderModeExZero
          border offset U = -1[m]
file:    handmade_sloped.crg

default settings

Example 3:

options: border mode U = dCrgBorderModeExKeep
file: handmade_sloped.crg

default settings

Example 4:

options: border mode U = dCrgBorderModeExRepeat
file: handmade_sloped.crg

default settings

Refer to protection notice DIN ISO 16016. Use of this data is subject to the OpenCRG public license policy.
Example 5:

options: border mode U = dCrgBorderModeExReflect
file: handmade_sloped.crg

Example 6:

options: border mode U = dCrgBorderModeExRepeat
border offset U = 1[m]
file: handmade_sloped.crg

Refer to protection notice DIN ISO 16016. Use of this data is subject to the OpenCRG public license policy
Example 7:

**options:** border mode V = dCrgBorderModeNone

**file:** handmade_vtest.crg

**default settings**

**option settings**

Example 8:

**options:** border mode V = dCrgBorderModeExZero

**file:** handmade_vtest.crg

**default settings**

**option settings**
Example 9:

**options:** border mode V = dCrgBorderModeExKeep

**file:** handmade_vtest.crg

default settings

![Default settings graph]

option settings

![Option settings graph]

Example 10:

**options:** border mode V = dCrgBorderModeExRepeat

**file:** handmade_vtest.crg

default settings

![Default settings graph]

option settings

![Option settings graph]
Example 11:

options: border mode \( V = \text{dCrgBorderModeExReflect} \)

file: handmade_vtest.crg

default settings

Example 12:

options: border mode \( V = \text{dCrgBorderModeExRepeat} \)

border offset \( V = 1[m] \)

file: handmade_vtest.crg

default settings
4.2.8.2 Smoothing Zones

In order to provide a smooth on-set and/or off-set of z data, the begin and end of the data (including slope and bank) may be scaled linearly from zero to full size within a user-defined range at either end of the core area. Again, core area is the original data extent defined in the data file which is not subject to the evaluation via one of the border modes described in the previous chapter.

The parameters of the smoothing zone may be defined via the following interfaces:

<table>
<thead>
<tr>
<th>symbolic constant</th>
<th>C-API data type</th>
<th>values</th>
<th>data file name</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>dCrgCpOptionSmoothUBegin</td>
<td>double</td>
<td>0.0..u_max</td>
<td>BORDER_SMOOTH_UBEG</td>
<td>0.0..u_max</td>
</tr>
<tr>
<td>dCrgCpOptionSmoothUEnd</td>
<td>double</td>
<td>0.0..u_max</td>
<td>BORDER_SMOOTH_UEND</td>
<td>0.0..u_max</td>
</tr>
</tbody>
</table>

**Example 1:**
- options: smoothing zone at begin = 5[m]
- file: handmade_platform.crg

**Example 2:**
- options: smoothing zone at end = 5[m]
- file: handmade_platform.crg
4.2.8.3 Continuation of Reference Line

For points whose u position exceeds the data set’s valid range (i.e. the original reference line), the corresponding x/y position is usually computed by extrapolating the reference line at the respective end. However, reference lines representing a closed track, the extrapolation of the u position may be achieved by trying to close the reference line and, thus, position the point (again) within the core area of the data set.

“Track can be closed if both extrapolated lines intersect with bend angle < 60deg
• each other
• refline orthogonals at begin and end
• Indicator: data.dved.ulex > 0

Track cannot be closed in all other cases.
• Indicator: data.dved.ulex = 0

For closed CRG track evaluation, the above condition has to be fulfilled, and the closing parameter has to be set.” (Rauh 2012, s.3)

The parameters controlling this behavior are:

<table>
<thead>
<tr>
<th>symbolic constant</th>
<th>C-API data type</th>
<th>values</th>
<th>data file name</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>dCrgCpOptionRefLineContinue</td>
<td>int</td>
<td>dCrgRefLineExtrapolate</td>
<td>REFLINE_CONTINUATION</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>dCrgRefLineCloseTrack</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

Dr. Rauh, J.: “Disclosing some more OpenCRG secrets ...”. Presentation from the 2nd OpenCRG Workshop in Munich, 14/03/2012, Slide 3

Example 1:

options: reference line continuation = dCrgRefLineExtrapolate
file: handmade_circle.crg

default settings

option settings

![default settings diagram]

![option settings diagram]
4.2.8.4 Curvature Evaluation

When computing the curvature at a given u/v-position, the resulting value is, per default, the actual curvature at the position. An option is available which, when enabled, returns the curvature at the corresponding reference line position instead of the curvature at the actual position.

The parameters controlling this behavior are:

<table>
<thead>
<tr>
<th>symbolic constant</th>
<th>C-API data type</th>
<th>values</th>
<th>data file name</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>dCrgCpOptionCurvMode</td>
<td>int</td>
<td>dCrgCurvLateral dCrgCurvRefLine</td>
<td>n/a</td>
<td></td>
</tr>
</tbody>
</table>

4.2.8.5 History Manipulation

The performance of data evaluation is increased by using internally a history of recently queried points. It is assumed that new queries typically occur in the vicinity of previous queries.

If the user has more knowledge about the u-positions of the reference line where the next queries will occur, he may pre-load the history with this information and, thereby, increase the performance of the next queries significantly.

The parameters controlling this behavior are:

<table>
<thead>
<tr>
<th>C-API symbolic constant</th>
<th>C-API data type</th>
<th>values</th>
<th>data file name</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>dCrgCpOptionRefLineSearchU</td>
<td>double</td>
<td>0.0..u_max</td>
<td>REFLINE_SEARCH_INIT_U</td>
<td>0.0..u_max</td>
</tr>
<tr>
<td>dCrgCpOptionRefLineSearchUFrac</td>
<td>double</td>
<td>0.0..1.0</td>
<td>REFLINE_SEARCH_INIT_U_FRACTION</td>
<td>0.0..1.0</td>
</tr>
</tbody>
</table>

4.2.8.6 History Search Criteria

While evaluating history information, the algorithms check for two distances of an actual position to a position stored in the history. Depending on whether a point is within a close or a far range of a point in history, the algorithm may simplify the search and, thus, return much faster with the correct result.
The parameters controlling this behavior are:

<table>
<thead>
<tr>
<th>symbolic constant</th>
<th>C-API data type</th>
<th>values</th>
<th>data file name</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>dCrgCpOptionRefLineClose</td>
<td>double</td>
<td>default: 0.3</td>
<td>REFLINE_SEARCH_CLOSE</td>
<td>default: 0.3</td>
</tr>
<tr>
<td>dCrgCpOptionRefLineFar</td>
<td>double</td>
<td>default: 2.2</td>
<td>REFLINE_SEARCH_Far</td>
<td>default: 2.2</td>
</tr>
</tbody>
</table>

4.3 The Tools

4.3.1 Overview

In the Tools/ directory, a set of samples for the usage of the C-API is provided as source code. The tools and their purposes are shown in the following list:

+-Tools .............collection of tools for an easy entry into the OpenCRG programming
  +--EvalOptions.....a set of routines demonstrating the usage of various options
  +--EvalXYnUV.......a set of routines for the evaluation of OpenCRG reference lines
  +--Eval2............an advanced example for the evaluation of OpenCRG data
  +--Reader............a sample application for a CRG file reader
  +--Simple............a really simple application covering all basics of the API,

Each tool's sub-directory is of identical structure:

+-ToolName ....sub-directory of a tool
  | +-src ..........all source files required for the tool
  | | +-inc ........all include files required for the tool (except for BaseLib includes)
  | | +-obj ........the resulting object files
  | | +-Makefile ...the makefile for compilation of the tool

Once a tool is compiled, its executable file will be located in Tools/bin.

4.3.2 Simple

This is a very simple example for the usage of the C-API.

executable: crgSimple

command line: crgSimple [options] <CRG data file>

options: -h show online help

4.3.3 Reader

Read a file and print some debug information.

executable: crgReader

command line: crgReader [options] <CRG data file>

options: -h show online help
4.3.4 Co-ordinate conversion x/y and u/v

Perform a series of conversions between x/y and u/v co-ordinate and check for consistency. The routines adapt automatically to the contents (i.e. extents) of the data file.

executable: crgEvalxyuv

command line: crgEvalxyuv [options] <CRG data file>

options: -h show online help

4.3.5 Evaluation of z Data

Perform a series of z data queries. The routines adapt automatically to the contents (i.e. extents) of the data file.

executable: crgEvalz

command line: crgEvalz [options] <CRG data file>

options: -h show online help

4.3.6 Application of Options and Modifiers

Perform a single test or series of tests involving data set modifiers or evaluation options. This test program is used for acceptance tests before a new version of the C-API is released.

executable: crgEvalOpts

command line: crgEvalOpts [options] <CRG data file>

options: -h show online help
-t <n> run the single test with the given number (please check the source code for the numbers and the corresponding test routines)
-p write the results (x/y/z data) into the file "crgPlotFile.txt" which may be used as input to gnuplot or other data visualizers

In order to facilitate the execution of various tests involving modifiers and options, two scripts are provided in the Tools/bin directory.

testOptions.sh
testModifiers.sh

These scripts run all available tests for modifiers and options, asking the user for confirmation of each test. The results are stored in a file named testReport.txt. The test tool used by the scripts is crgEvalOpts.
5 The OpenCRG® Matlab Tools

5.1 Getting Started

5.1.1 Downloading the Software Package
The latest version of the OpenCRG® Matlab Tools may be retrieved via the website

www.opencrg.org

Go to the Downloads area and look for the section Packages and Tools. There, you will find a package containing the C-API, MATLAB routines, documentation and sample files. Download this package and unpack it into a dedicated directory on your machine.

The Matlab Tools are located in the sub-directory

OpenCRG/matlab

The latest developer version may be retrieved via the OpenCRG® project managing and issue tracking-system. You can reach this system by going to

http://tracking.vires.com (registration required)

5.1.2 Release Notes
The release notes are part of the software package and will not be transferred to this document. Please look for the “readme.txt” files in the root directory of the OpenCRG package and in the Matlab Tools sub-directory.

5.1.3 Contents of the Package
The OpenCRG® Matlab Tools are delivered as a zipped package which, after unpacking, provides the following file structure:

|--crg_init.m.............initializes the CRG Matlab environment
|--crg_intro.m............introduction to the basic CRG concept and data structure
|--demo...................demo sources explaining the usage of the basic library
|--lib....................base library including functionality to read, evaluate, visualize, analyse, generate, modify and write CRG data files.
|--test...................test sources to validate the basic library
5.1.4 Working with OpenCRG® Matlab Tools

5.1.4.1 Initialization
Start OpenCRG environment by running crg_init.m from the Matlab command line

```
run <path-to-OpenCRG>/matlab/crg_init
```

To run the tests and demos, it is recommended to change to the work directory for temporary data

```
cd <path-to-OpenCRG>/temp
```

5.1.4.2 Getting Help
The OpenCRG® Matlab files contain the Matlab specific help header as well a copyright notices. Use help to view declaration and explanation of the methods.

```
help <OpenCRG-method>
```

To get an overview on CRG data organization, run the 'crg_intro' command.

```
crg_intro
```

5.1.5 Formatting M-File Comments
OpenCRG® uses the same formatting comments like Matlab does for publishing. Please refer to the Matlab product help of ‘Formatting M-File Comments for Publishing’ for detailed information.

5.1.6 Demos
Several demo scripts are provided in ‘<path-to-OpenCRG>/matlab/demo’. Running the crg_demo command will generate some CRG data structures, write them to disk, read them again, and optionally visualizes some contents. It may be useful to look into crg_demo to get some first examples how to use the OpenCRG Matlab functions and tools suite. For quite all basic test it is necessary to generate the sample demos by:

```
crg_demos
```

5.1.7 Basic Tests
Several test scripts are provided under ‘<path-to-OpenCRG>/matlab/tests’. A series of very brief tests can be run. These are also used for acceptance tests of the OpenCRG® Matlab Tools as well as benchmark tests for the C-API. CRG demo files are used to test the functionality. Make sure all sample demos are generated by running crg_demos.

```
crg_demos % if not done before once
crg_test_<functionname>
```

5.1.8 Publishing script files
The OpenCRG® Tool suites script files are written and comment in Matlab style for publishing. This publishing functionality should be used to produce adequate output. Since R2008a Matlab’s “publish configurations” was introduced by Mathworks. It allows to publish to latex, doc and HTML style.
5.1.8.1 Extensible stylesheet language (xsl)
A sample xsl-file is located in `<path-to-OpenCRG>/docsrc/xsl/`. Publishing to latex using the xsl file produces the same formatted output like the OpenCRG® tool suite pdf’s.

5.1.8.2 Publish to pdf (Linux)
A simple makefile is provided to generate pdf’s from Matlab files in

`<path-to-OpenCRG>/docsrc/make/`

Publish your scripts to latex output using the OpenCRG® extensible stylesheet language file

`<path-to-OpenCRG>/docsrc/xsl/openCRG_mxdom2latex.xsl`

. Make sure you select `.jpg` as image type. Copy the makefile into your destination folder and execute it by:

```
make <function_name>.pdf
```

The Makefile will copy the pdf in a subdirectory `./pdf`. Make sure `pdflatex` is installed.

Use make clean to delete all latex generated files beside the Makefile.

5.1.8.3 Hint on memory limitations
With 32bit Matlab available memory is sometimes rather limited, especially on WIN32 systems, see Matlab help on memory.

On a typical WIN32 installation with 4GB, only 440MB of continuous memory was available (use `feature('memstats')` to show on your system). This allows to work on 220MB CRG files, with e.g. 1cm x 1cm resolution, 4m with and 1.4km length. On Linux32, at least double file sizes can be handled. On all 64bit installations, there is virtually no limitations in CRG size.
5.2 The Base Library

5.2.1 Overview
The base library contains a large set of routines similar to the C-API for

- reading
- modifying
- evaluating

and is extended by methods to

- visualize
- generate
- analyse

OpenCRG® data.

5.2.2 Demo Files
The Tool suite comes with basic script files

matlab/demo/crg_demo.m
matlab/demo/crg_demo_gen*.m

Run 'crg_demo.m' to generate a set of simple crg-files. These are used to execute the test files. The second set of demo files show how to generate a crg-file with a smooth reline and surface data.

5.2.3 Test Files
A set of test files are provided to verify the functionality of the tool suite and are located in

'/matlab/test':

crg_test_append.m  concatenate two crg files
crg_test_continuesTrack.m  road continuation
crg_test_eval_uv2iuiv.m  cut crg file
crg_test_ext_sb.m  extract slope and/or banking
crg_test_filter.m  filter crg file
crg_test_gen_csb2crg.m  additional synthetically generated crg files
crg_test_gen_road.m  generate and write synthetically crg file
crg_test_isequal.m  compare two crg files if equal
crg_test_limiter.m  limits crg z-values
crg_test_map_uv2uvAxy2xy.m  uv and inertial mapping
crg_test_options.m  add options
crg_test_peakfinder.m  find peaks
crg_test_rerender.m  re-render crg-file

5.2.4 Library Files
The library is composed of the following Matlab files which are located in 'matlab/lib'.

5.2.4.1 Analysis tools:

crg_isequal.m  comparison if two crg files are equal

crg_peakfinder.m  find peaks
5.2.4.2 Evaluation tools:

- `crg_eval_u2crv.m`: evaluate curvature crv in reference line u position
- `crg_eval_u2phi.m`: evaluate heading phi in reference line u position
- `crg_eval_uv2iuiv.m`: evaluate index iu, iv of distance u,v
- `crg_eval_xy2uuv.m`: transform point in uv to xy
- `crg_eval_xy2z.m`: evaluate z at grid position uv
- `crg_wgs84_crg2html.m`: generate HTML file to show wgs info in Google maps
- `crg_wgs84_dist.m`: evaluate distance and bearing between WGS84 positions
- `crg_wgs84_invdist.m`: calculate WGS84 position by distance and bearing
- `crg_wgs84_setend.m`: set WGS84 end coordinate
- `crg_wgs84_wgs2url.m`: generate url string to show wgs info
- `crg_wgs84_xy2wgs.m`: transform point in xy to WGS84 using 2 references
- `crg_wgs84_xy2wgs.m`: transform point in xy to WGS84

5.2.4.3 Generation tools:

- `crg_check_uv_descript.m`: creates a cross section (v-) profile.
- `crg_gen_csb2crg0.m`: generate synthetically crg data
- `crg_gen_ppxy2phi.m`: generate refine heading out of polynomial
- `crg_gen_pxy2ppxy.m`: generates (smooth) polynomial through ref-points
- `crg_perform2surface.m`: add cell array to surface data

5.2.4.4 Modification tools:

- `crg_append.m`: appends two crg data sets
- `crg_b2z.m`: add banking to z-values of crgdata
- `crg_cut_iuiv.m`: separate a crg file
- `crg_ext_bank.m`: extract banking
- `crg_ext_slope.m`: extract slope
- `crg_filter.m`: filter crg data
- `crg_fip.m`: flips the crg contents
- `crg_generate_sb.m`: finds and generates slope and banking
- `crg_limiter.m`: limit crg data
- `crg_map_uv2uv.m`: map crg data in uv
- `crg_map_xy2xy.m`: inertial mapping
- `crg_mods.m`: apply modifiers on data
- `crg_rerender.m`: re-render crg data
- `crg_s2z.m`: add slope to z-values of crg data

5.2.4.5 Io-files tools:

- `crg_check.m`: base check class
- `crg_check_data.m`: check, fix and complement data
- `crg_check_head.m`: verifies crg struct head data
- `crg_check_mods.m`: verifies crg struct modification data
- `crg_check_opts.m`: verifies crg struct options data
- `crg_check_single.m`: single type check of core data
- `crg_read.m`: read crg file
- `crg_single.m`: single type conversion of core data
- `crg_wrap.m`: re-wraps heading angles to +/- pi range
- `crg_write.m`: road file writer
- `ipldemo.m`: IPLOS write/read demonstration
- `ipl_read.m`: IPLOS file reader
- `ipl_write.m`: IPLOS file writer
- `isd_add.m`: (structured data file) block add
- `isd_cut.m`: (structured data file) block cut
- `str_num2strn.m`: convert number to string of given length
5.2.4.6 Visualization tools:

- `copy_ax2fig.m` copy current axes object to new figure
- `crg_figure.m` figure setup
- `crg_plot_elgrid_cross_sect.m` plot road elevation grid cross sections
- `crg_plot_elgrid_limits.m` plot road elevation grid limits
- `crg_plot_elgrid_long_sect.m` plot road elevation grid long sections
- `crg_plot_elgrid_uvz_map.m` plot road elevation grid UVZ map
- `crg_plot_elgrid_xyz_map.m` plot road elevation grid XYZ map
- `crg_plot_refline_curvature.m` road refline curvature plot
- `crg_plot_refline_elevation.m` road refline elevation plot
- `crg_plot_refline_heading.m` road refline heading plot
- `crg_plot_refline_slope_bank.m` road refline slope and banking plot
- `crg_plot_refline_xy_map.m` road refline XY map plot
- `crg_plot_refpnt_distance.m` road refpoint distance plot
- `crg_plot_road_uv2uvz_map.m` plot road UVZ map
- `crg_plot_road_uv2xyz_map.m` plot road XYZ map
- `crg_plot_road_uvz_map.m` road UVZ map
- `crg_plot_road_xyz_map.m` road XYZ map
- `crg_show.m` road visualizer
- `crg_show_elgrid_cuts_and_limits.m` road elevation grid 2D visualizer
- `crg_show_elgrid_surface.m` road elevation grid 3D surface visualizer
- `crg_show_isequal.m` comparison of two crg_files data core visualizer
- `crg_show_info.m` read text info visualizer
- `crg_show_peaks.m` peak visualizer
- `crg_show_refline_elevation.m` road refline elevation visualizer
- `crg_show_refline_map.m` road refline map visualizer
- `crg_show_refpnts_and_refline.m` road refpnts and refline visualizer
- `crg_show_road_surface.m` road 3D surface visualizer
- `crg_show_road_uv2surface.m` road 3D surface visualizer by u,v grid
- `crg_surf.m` 3D surface plot
5.2.5 Working with Data Files

5.2.5.1 Simple Use Case

There are many operations that may be applied to OpenCRG® data sets. However, a simple way of using OpenCRG® data files is shown in just 2 stages:

1. load a crg file
2. call the evaluation methods

```
crg_demo % if not done before once
data = crg_read('demo1.crg'); % load crg file
pz = crg_eval_uv2z(data, [100 0]); % z-elevation on (u,v) = [100 0]
```

5.2.5.2 CRG data structure

This Matlab tools suite uses one structure which shall be briefly explained here. For further explanation run crg_intro.

```
data = ....................variable name
|----head...................struct array of data scalars
|----mods...................data, which defines further CRG modifiers
|----opts...................data, which defines further CRG processing options
|----ct....................cell array of comment text, required for file output
|----struct...............(optional) cell array of further structured data, used
|-------------------------------for file output, may contain opts data for later CRG
|-------------------------------file processing.
|----filenm.................name of read crg data file
|----z......................array(nu, nv) of z (height) values (single)
|----v......................vector of v values (single)
|----b......................(optional) vector of banking values (single)
|----u......................vector of u values (single)
|----p......................(optional) vector of phi values (single)
|----s......................(optional) vector of slope values (single)
```

Not all structure fields are required and some are derived by ‘crg_check_*’ routines. A minimum CRG content consist of struct fields u, v and z. All necessary extended data can than be derived by the ‘crg_check’ routine.

```
data = struct; % empty struct
data.z = single(repmat(0.01*peaks(101), 2, 1)); % z values
data.u = 2.01; % set u-space
data.v = 0.5; % set v-space
data = crg_check(data); % get derived data
crg_show(data); % display result
```
5.2.5.3 Modifiers and Options

In simple cases, data sets will be read from file and evaluations may take place immediately. However, the user may want to vary the way a specific data set is evaluated without having to modify the original data (i.e., the data file) itself.

For this purpose, modifiers and options have been introduced.

- **Modifiers** modify a copy of OpenCRG® data which is stored in memory and, therefore, provide the modified data for all subsequent evaluation requests.

- **Options** influence the way a specific query is performed without modifying any of the data stored in memory.

In the data struct, modifiers are found in the substructure crg.mods and options are found in crg.opts. The tool suite provides discrete calls for setting modifiers and options. Evaluation methods take account if options are set.

Modifiers have to be executed by calling the crg.mods() routine, which will affect the modifier settings on crg-data.
5.2.6 Modifiers

As mentioned above, the OpenCRG® data struct contains the so called 'modifiers' which globally modify the crg-data. All modifier functionalities are equal to the C-API and explained there. Further details about the Matlab API are located in crg_intro or in the help content of the function.

CRG scaling (default: no scaling)
- scale elevation data
  szgd    scale elevation grid
  sslp    scale slope information
  sbkg    scale banking information
- scale reline data (resets reline position to origin)
  slth    scale u information
  swth    scale v information
  scrv    scale reference line’s curvature
CRG elevation grid NaN handling
  gnan    how to handle NaN values (default: 2)
          = 0: keep NaN
          = 1: set zero
          = 2: keep last value in cross section
  gnao    z offset to be applied at NaN positions (default: 0)
CRG re-positioning: reline by offset (default: "by refpoint")
  rlox    translate by rlox
  rloy    translate by rloy
  rloz    translate by rloz
  rlop    rotate by rlop around (xbeg, ybeg)
CRG re-positioning: reline by refpoint (overwrites "by offset")
- position \((u,v)\) on reference line:
  rpfu    relative u (default: 0)
  rptu    absolute u
  [with optional: rpou (default: 0)]
  rptv    absolute v (default: 0)
  [with optional rpov (default: 0)]
- position \((x,y,z)\) and orientation (phi) in inertial frame:
  rptx    target position (default: 0)
  rpty    target position (default: 0)
  rptz    target position (default: 0)
  rptp    target orientation (default: 0)

Modifiers are evaluated by the ‘crg_mods()’ routine. The mods are evaluated in sequence as they appear below, and are cleared after they are applied. An empty mods array inhibits any default settings. Make sure that you create a new struct for a new modifier set. The example below shows how to set up a modification.

```matlab
data = crg_read('demo1.crg');
data.mods = struct;
data.mods.gnan = 1;
data = crg_mods(data);
```

Refer to protection notice DIN ISO 16016. Use of this data is subject to the OpenCRG public license policy.
5.2.7 Options

As mentioned above, the OpenCRG® data struct contains also the so called 'options' which are applied during evaluation, not globally. All modifier functionalities are equal to the C-API and explained there. Further details about the Matlab API are located in 'crg_intro' or in the help content of the function.

CRG elevation grid border modes in u and v directions
bdmu at beginning and end (default: 2)
bdmv at left and right side (default: 2)
= 0: return NaN
= 1: set zero
= 2: keep last
= 3: repeat
= 4: reflect
bdou z offset beyond border (default: 0)
bdov z offset beyond border (default: 0)
bdss smoothing zone length at start
bdse smoothing zone length at end

CRG reference line continuation
rflc how to extrapolate (default: 0)
= 0: follow linear extrapolation
= 1: close track

CRG reference line search strategy
sfar far value (default: 1.5)
scls close value (default: sfar/5)

CRG message options
wmsg warning messages (default: -1)
wcvl local curvature limit exceeded (d:-1)
wcvg global curvature limit exceeded (d:-1)
ormsg log messages (default: -1)
leva evaluation inputs and results (default: 20)
lef how often (default: 1)
lhst refine search history (default: -1)
lhsf how often (default: 100000)
lsta evaluation statistics (default: -1)
lstf how often (default: 100000)

CRG check options
ceps expected min. accuracy (default: 1e-6)
cinc expected min. increment (default: 1e-3)
ctol expected abs. tolerance (default: 0.1*cinc)

5.3 Tools

5.3.1 crg_gen_csb2crg0: Generate synthetic roads
‘crg_gen_csb2crg0’ allows to simple generate crg-files including slope [s], banking [b] and curvature [c] in MATLAB.

\texttt{crg\_gen\_csb2crg0( inc, u, v, c, s, b )}

The minimal input parameter are increment [inc] and length information in \textit{u,v} direction.

\texttt{data = crg\_gen\_csb2crg0( [1,0.5], 100, 2);}

Please also see ‘crg\_test\_gen\_csb2crg0’, ‘crg\_test\_gen\_road’, ‘crg\_demo\_gen\_sl’ and ‘crg\_demo\_gen\_syntheticStraight’ for additional examples handling synthetic road generation.
5.3.1.1 Cross sections

Creating non equidistant cross sections (v) is up to the developer. Nevertheless the OpenCRG – Matlab Api provides several demonstrations (‘crg_demo_gen_sl’ ) how a readable v-profile could be set up.

The task is devided into two steps.

1. Create readable profiles ( yourself )
2. Generate v-profile for crg_gen_csb2crg0.m ( ‘crg_check_uv_descript.m’ )

5.3.1.2 Create profile(s)

The next example shows one possibility to create profiles. Please note the comments for explanation.

```matlab
% STEP 1: create longitudinal and lateral profile(s) like this
% u ---> coordinate begin middle sections end
% l ---> left hand side
% r ---> right hand side
% w ---> width of whole road
% c ---> center of road
% p ---> profile
% r --> roughness
% _ -> name_sect
% _ -> name_prof
% offset or amplitude to origin
% uwp_road_sect = [ ubeg uend ]; % road width u sections
% uwp_road_prof = 1 * [ ones(size(uwp_road_sect)] ; % road width v sect
% ultr_road_sect = [ ubeg uend ]; % left lane u sections
% ultr_road_prof = [ 1 1 ]; % left lane v sect
% urp_road_sect = [ ubeg uend ]; % right lane u sections
% urp_road_prof = [ 1 1 ]; % right lane v sect
% vwp_road_sect = [ ubeg uend ]; % road width v sect
% vwp_road_prof = [ 1 1 ]; % road width v sect
% vlr_road_sect = [ ubeg uend ]; % left lane v sect
% vlr_road_prof = [ 1 1 ]; % left lane v sect
% vlp_road_sect = [ ubeg uend ]; % left lane v sect
% vlp_road_prof = [ 1 1 ]; % left lane v sect
% vpr_road_sect = [ ubeg uend ]; % left lane v sect
% vpr_road_prof = [ 1 1 ]; % left lane v sect
% vr_road_sect = [ ubeg uend ]; % right lane v sect
% vr_road_prof = [ 1 1 ]; % right lane v sect
%
% mode one of {'Profile' 'Random' 'Ignore'}
% u ---> coordinate v section v profile
% l ---> left hand side v section v profile
% r ---> right hand side v section v profile
% w ---> width of whole road v section v profile
% c ---> center of road v section v profile
% p ---> profile v section v profile
% r --> roughness v section v profile
% _ -> name_sect v section v profile
% _ -> name_prof v section v profile
% offset or amplitude to origin v section v profile
% uwp_road_sect = [ ubeg uend ]; % road width u sections
% uwp_road_prof = [ 1 1 ]; % road width v sect
% ultr_road_sect = [ ubeg uend ]; % left lane u sections
% ultr_road_prof = [ 1 1 ]; % left lane v sect
% urp_road_sect = [ ubeg uend ]; % right lane u sections
% urp_road_prof = [ 1 1 ]; % right lane v sect
% vwp_road_sect = [ ubeg uend ]; % road width v sect
% vwp_road_prof = [ 1 1 ]; % road width v sect
% vlr_road_sect = [ ubeg uend ]; % left lane v sect
% vlr_road_prof = [ 1 1 ]; % left lane v sect
% vlp_road_sect = [ ubeg uend ]; % left lane v sect
% vlp_road_prof = [ 1 1 ]; % left lane v sect
% vpr_road_sect = [ ubeg uend ]; % left lane v sect
% vpr_road_prof = [ 1 1 ]; % left lane v sect
% vr_road_sect = [ ubeg uend ]; % right lane v sect
% vr_road_prof = [ 1 1 ]; % right lane v sect
%
% refer to protection notice DIN ISO 16016. Use of this data is subject to the OpenCRG public license policy
% end of user settings
% STEP 2: create and check lateral profile vector

v = crg_check_uv_descript(uv_mue, {'Ignore' 'Profile' 'Random'});
```

5.3.1.3 Create profile vector

OpenCRG provides a functionality to extract the cross section vector defined above. For further details see ‘crg_check_uv_descript.m’.
5.3.1.4 Curvature

Curvature can be divided into sections independent of banking and slope. It is described by a polynomial of grade 2. The following represents a possible curvature matrix definition.

\[
c = \{ \text{LC1} \{ \frac{1}{R_{1s}} (\frac{1}{R_{1e}} - \frac{1}{R_{1s}}) / \text{LC1} \} \ldots \\
\text{LC2} \{ \frac{1}{R_{2s}} (\frac{1}{R_{2e}} - \frac{1}{R_{2s}}) / \text{LC2} \} \ldots \\
\ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 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5.3.1.7 Coherence of azimuth direction angle alteration, curve radius and clothoid parameter
( Based on Dr. Klaus Müller (Daimler AG) considerations to calculate sensible parameter for road construction )

\[ \Delta \Phi = \Phi_4 - \Phi_1 = (\Phi_2 - \Phi_1) + (\Phi_3 - \Phi_2) + (\Phi_4 - \Phi_3) \]

\[ \Delta \Phi = \frac{L_1}{2R} + \frac{L_2}{R} + \frac{L_3}{2R} \]

with \( R \) = radius
\( L_1 \) = length clothoid 1
\( L_2 \) = length circular arc
\( L_3 \) = length clothoid 2

common in road construction:

\[ \frac{1}{3} R \leq L_1 \leq R \]
\[ \frac{1}{3} R \leq L_3 \leq R \]

hence \( L_{1,2} = f_{1,2} \cdot R \)
choose \( 0 \leq f_{1,2} \)
yields to

\[ \Delta \Phi = \frac{f_1}{2} + \frac{L_2}{R} + \frac{f_3}{2} \cdot \frac{L_2}{R} = \Delta \Phi - \frac{1}{2} (f_1 + f_3) \]