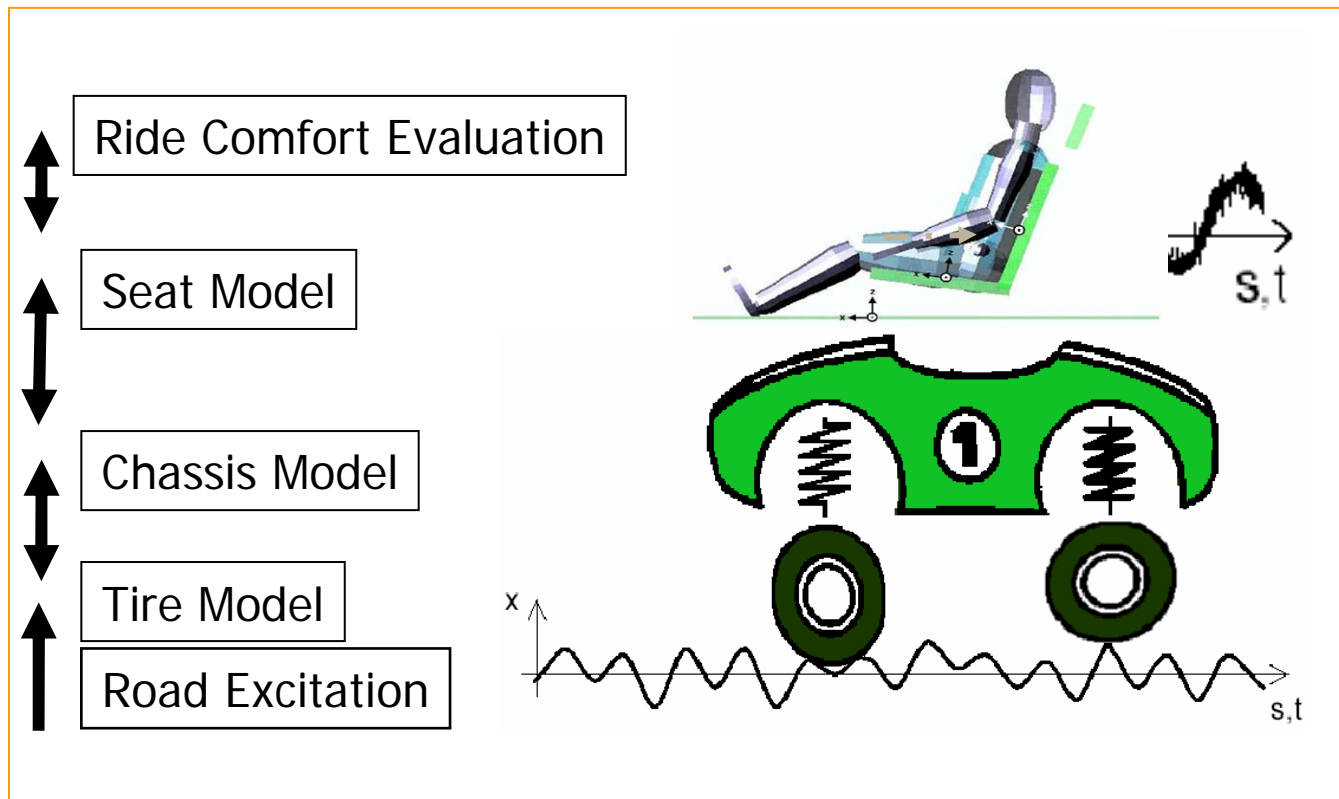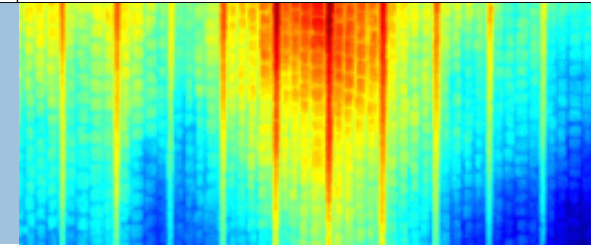# DAIMLERCHRYSLER

**Road Simulation
CRG (curved regular grid) Road Data Format
Overview**

Dr. Jochen Rauh, Helmut Gimmler
25.11.2005 / 20.03.2007

Motivation

Ride Comfort Evaluation

Seat Model

Chassis Model

Tire Model

Road Excitation

Simulation of

- **Ride Comfort**

- **Vehicle Handling**

- **Durability Load Profiles**

Road Measurements- Today

- Vehicle for high-resolution measurements of road surfaces in moving traffic was developed by DaimlerChrysler Research and Technology

- Vehicle is now operated by TÜV SÜD Automotive GmbH to provide measurements to everyone[1].

- See also: Gimmler, Rauh, Ammon: Straßenprofile: Mobile Messung, prozessgerechte Datenaufbereitung und vollständige Bewertung bereiten die Basis für eine effektive Simulation (Road Profiles: Mobile Measurement, Data Processing for Efficient Simulation and Assessment of Road Properties). In "Reifen-Fahrwerk-Fahrbahn Hannover 25./26.10.2005, VDI-Bericht 1912, VDI-Verlag, Düsseldorf, 2005"


[1] http://www.tuev-sued.de/3D-Track

Preprocessing of 3D Data Motivation

- Measurements results are road cross sections with slightly varying distances and orientations due to vehicle motions.

- Preprocessing transforms data to efficient representation for further simulation use:

    - Storage need for 1km x 2m road with surface resolution of 1cm x 1cm < 80MB.

    - Consistency of data guaranteed, no further steps (e.g. triangularization) needed.

    - Evaluation during simulation 10...100 times faster than so far used approaches.

v

u

✕ = Measurements
✕ = regularized grid ponts
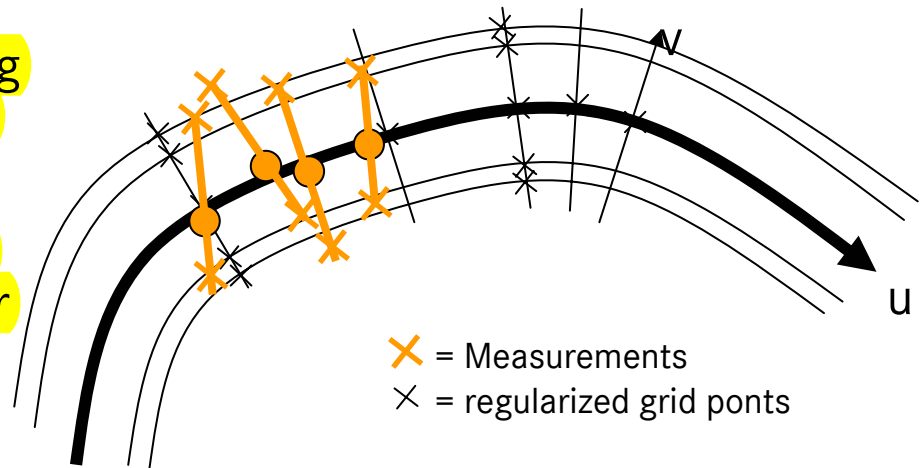
Preprocessing of 3D Data
Step 1
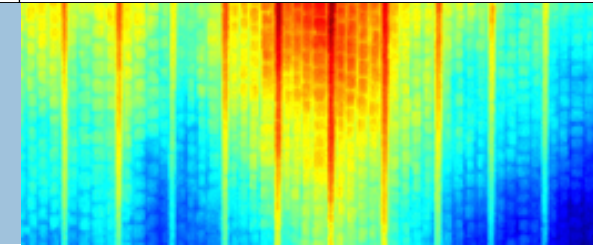
- smoothen curvature (eliminate higher frequency contents of measurements vehicle's movements)
- derive smooth road reference line with minimal lateral displacement from vehicle trajectory
- Discretize reference line into a equidistant point sequence

smoothed road curvature to be used for road reference line

measurements

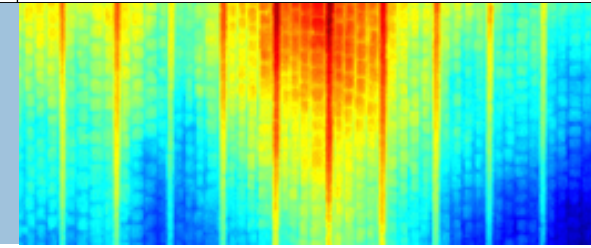road length
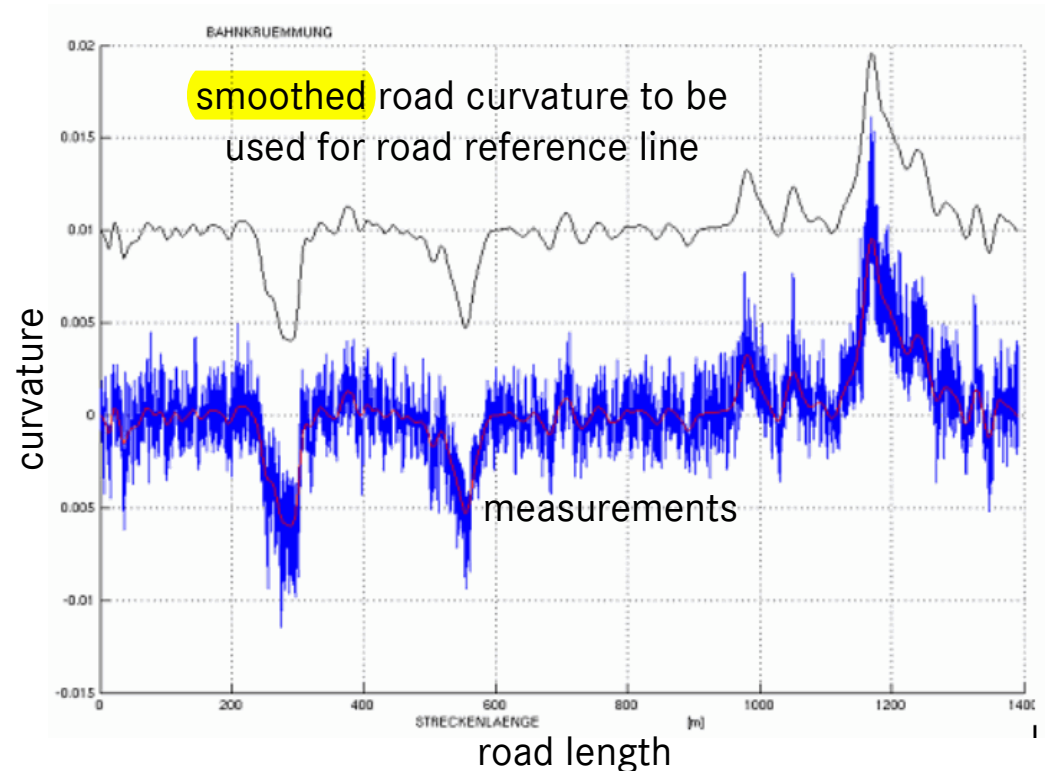
Preprocessing of 3D Data
Step 2

- Determine virtual cross cuts orthogonal to smoothed reference line in all equidistant points
- Generate evaluation points on these cross cuts for to achieve the target CRG-Grid-resolution
- Interpolate the 3D road surface given by the measurement points at the CRG-Grid-Point locations (e.g. by Matlab griddata function)
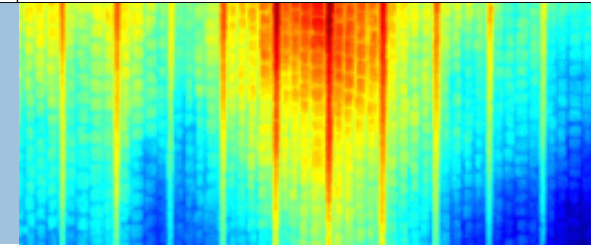

CRG-Grid-Points
Original Measurement Points
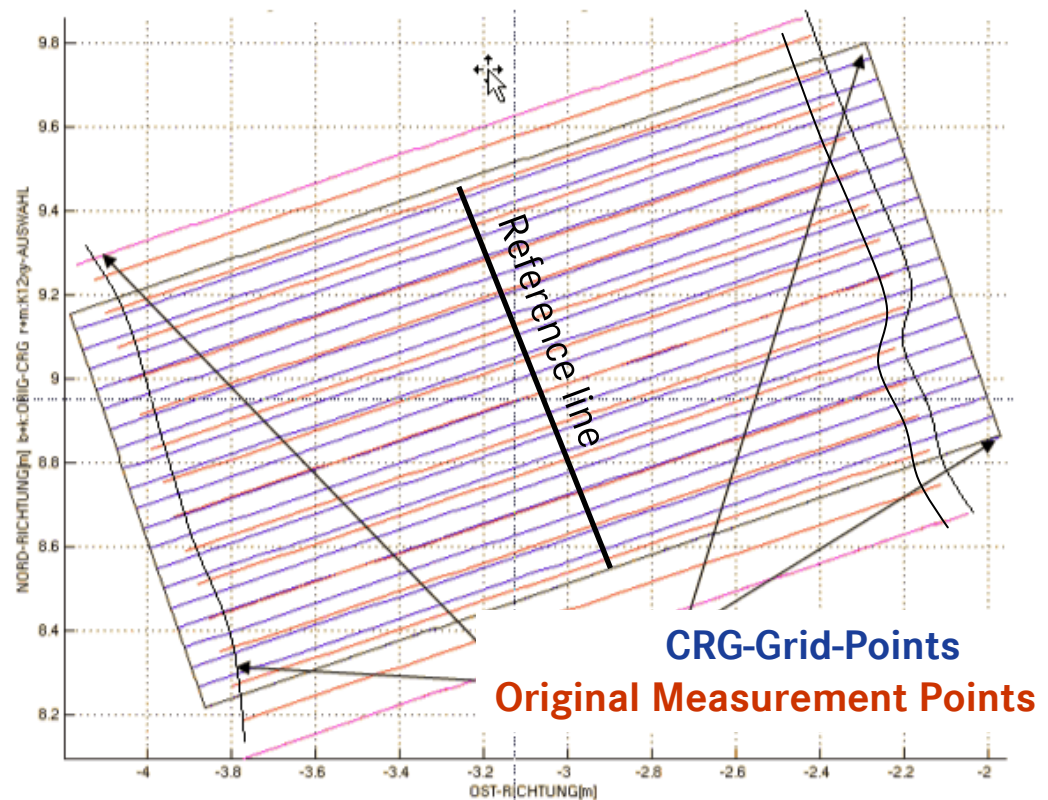
CRG (curved regular grid) Overview Fundamental Idea

Curved Reference Line
x(u), y(u)

CRG
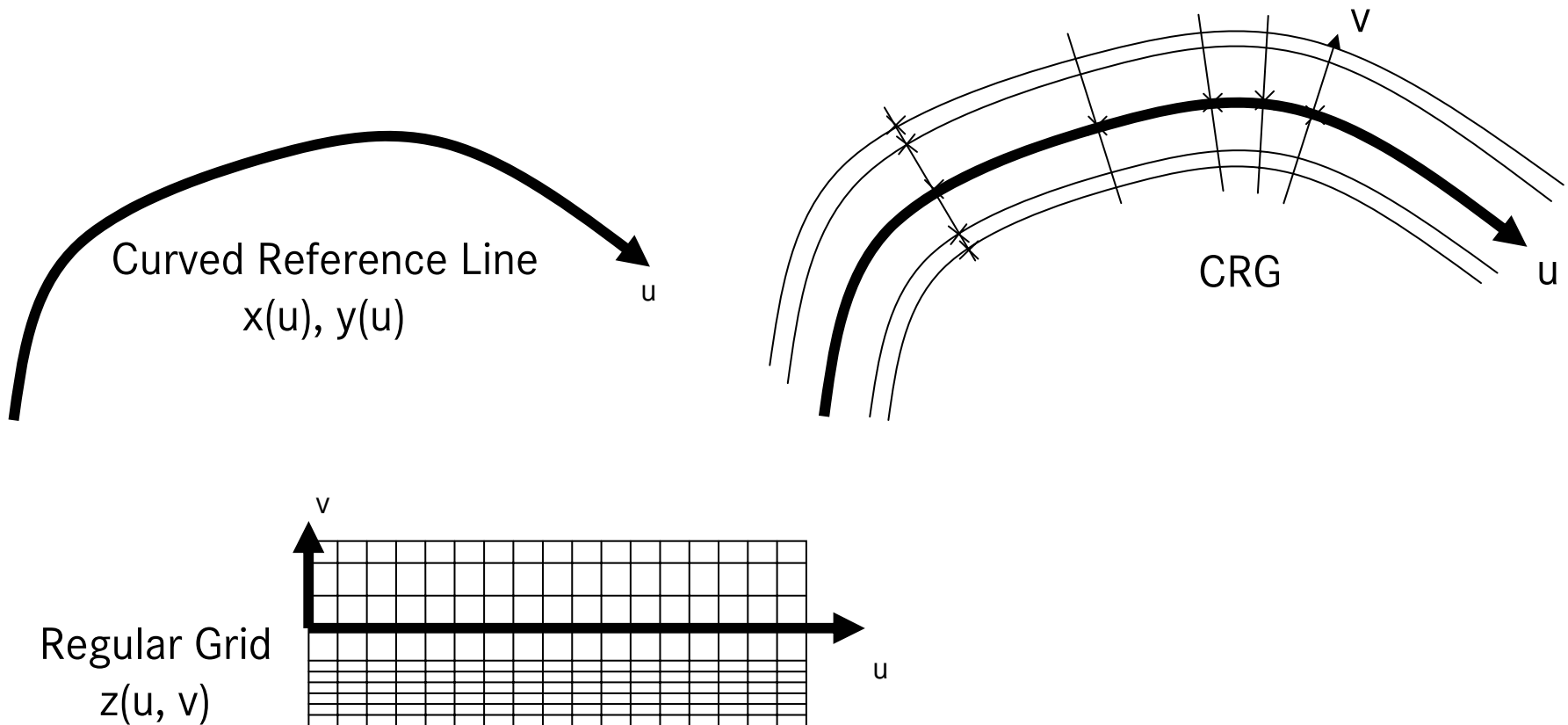
Regular Grid
z(u, v)

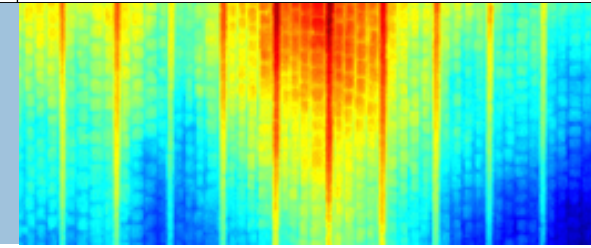# CRG (curved regular grid) Overview Application Field

3D road surfaces

- Height information close to a reference line

- Reference line can be used as input for steering control / driver models

Extension to other environmental information possible:

- All static information like friction μ-value, temperature, stationary wind velocity/direction can be handled similarly.

CRG (curved regular grid) Overview Data Content – Basics

1. Reference Line

- (x, y)-pairs in constant distance:
  - seems to be most evident approach, but
  - due to accuracy problems not suited to represent longer tracks: the resulting distances or curvatures are much disturbed by bit noise (small differences on big absolute values)

- Heading angle between points of fixed distance:
  - no accuracy problem even for long tracks
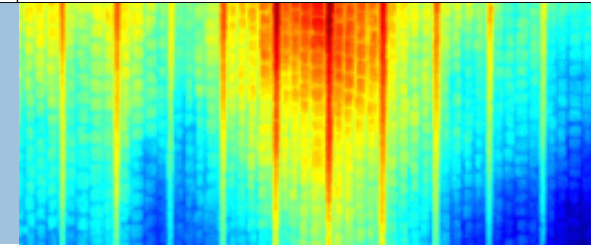 - (reduced file size)

2. Height Information

- Road cross cuts orthogonal to reference line
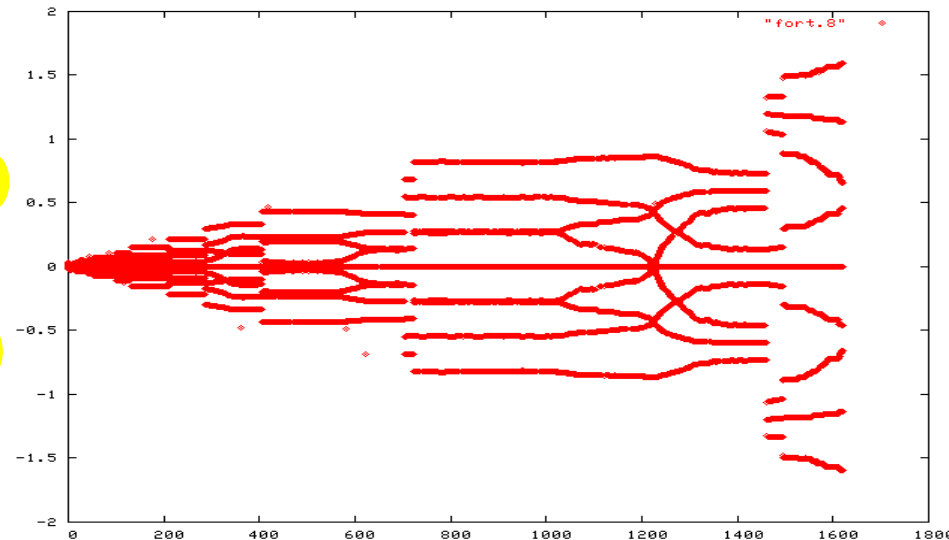
Typical curvature "picture" due to bit noise for a 1800 m track defined by (x, y)-float-pairs. Instead of a smooth curvature line with absolute values up to 0.04 m^{-1} for the given 25 m road radius, the local curvature values are disturbed by bit noise upto 1,5 m^{-1}, which makes it un-usable.

# CRG (curved regular grid) Overview
Data Content

- z-array:
  - z(nu, nv)   height values at grid points (may contain NaNs)
- u-axis (reference line)
  - ubeg   start coordinate (default: 0.00m)
  - uend   end coordinate
- v-axis (orthogonal to reference line)
  - vmin, vmax   v value at right/left edge of road (equally spaced v-axis), or
  - v(nv)   variably spaced v-axis
- phi (heading angle):
  - p   one phi value for straight reference line, or
  - p(nu-1)   phi values between reference line points
    distance between these points is (uend-ubeg)/(nu-1)
- r0 (reference line origin):
  - (x0, y0)   inertial coordinates (default: (0, 0))

CRG (curved regular grid) Overview ASCII representation example
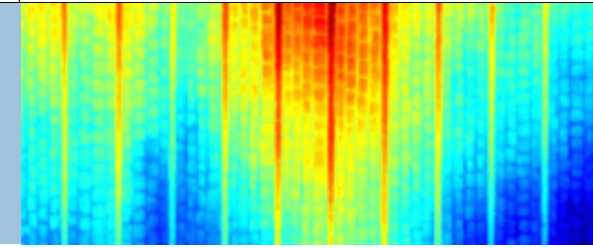
```
$CT                                            ! comment text block
crg file example for road surface description (width: 3m, length: 22m)
with curved referenceline and grid of (0.25m...1.0m) x 1.0m
$!*********************************************************************
$ROAD_CRG                                      ! 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
REFERENCE_LINE_END_X     = 21.953
REFERENCE_LINE_END_Y     = 1.209
REFERENCE_LINE_END_PHI   = 0.0
REFERENCE_LINE_INCREMENT = 1.0
LONG_SECTION_V_RIGHT     =-1.50
LONG_SECTION_V_LEFT      = 1.50
LONG_SECTION_V_INCREMENT = 0.25
$!*******************************
```

```
$KD_Definition                                         ! data definition block
#:LRFI                                  ! one of the men readable IPLOS formats
U:reference line x,m,0,1.0       ! undefined data, only for IPLOS viewing
D:reference line phi,rad
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
$!***********************************************************************
* phi        l_sec 1    l_sec 2    l_sec 3    l_sec 4    l_sec 5    l_sec 6    l_sec 7
*            v=-1.50    v=-1.25    v=-1.00    v= 0.00    v= 1.00    v= 1.25    v= 1.50
$$$$$$$$$$0$$$$$$$$$$0$$$$$$$$$$0$$$$$$$$$$0$$$$$$$$$$0$$$$$$$$$$0$$$$$$$$$$0$$$$$$$$$$0
0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000
0.0000000 0.0000000 0.0000000 0.0000000 0.0111111 0.0000000 0.0000000 0.0000000
0.0110000 0.0000000 0.0000000 0.0111111 0.0111111 0.0111111 0.0000000 0.0000000
0.0220000 0.0000000 0.0111111 0.0111111 0.0111111 0.0111111 0.0111111 0.0000000
…
```
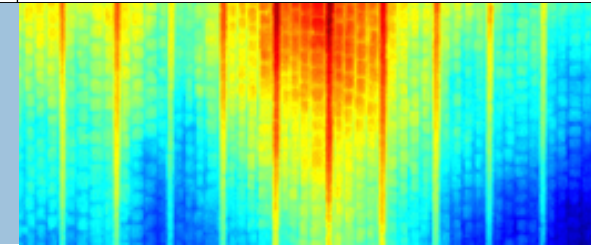
CRG (curved regular grid) Overview Implementation
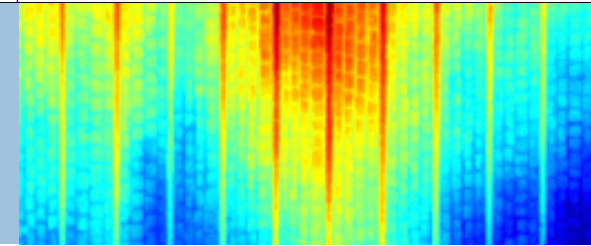
- The file format is based on an basic simulation result file format used at DaimlerChrysler since long. It is available on all (even historical) platforms from IBM-MVS, DEC-VMS to WIN and *ix.

- The Matlab demo routines (run on R13 and later) given to the public are suited to read, write and show valid CRG files:

  - crg_read: read CRG file contents to CRG Matlab structure

  - crg_write: write CRG Matlab structure contents to CRG file.

  - crg_show: show all relevant contents of a CRG Matlab structure.

  - crg_demo: generates, reads and shows some CRG files. This is a good starting point to learn how to use the demo routines.

CRG (curved regular grid) Overview
NaN handling

Handling of missing measurements:

- Missing measurements are only allowed at the left/right edges of the road, "holes" have to be corrected during data preprocessing.

- The missing z coordinates are represented by NaNs. The Matlab demo routines crg_write/ipl_write care about a CRG conform binary representation (x7FC00000 – Matlab sometimes uses also other representations)

- The missing points (and points outside the defined road) can be generated e.g. by just extrapolating the last valid value as a constant height.

CRG (curved regular grid) Overview Demo
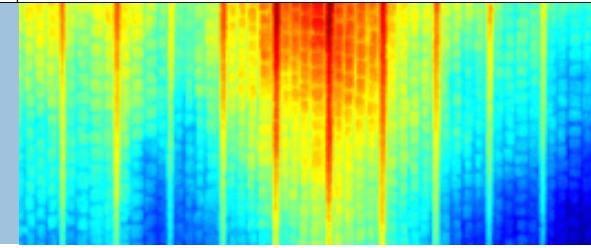
Figure 1 of: `crg_show(crg_read('../crg/demo_real.crg'))`

- The reference line coordinate u runs from 730m to 740m

- we can see the heading angle decreasing by 20 deg.
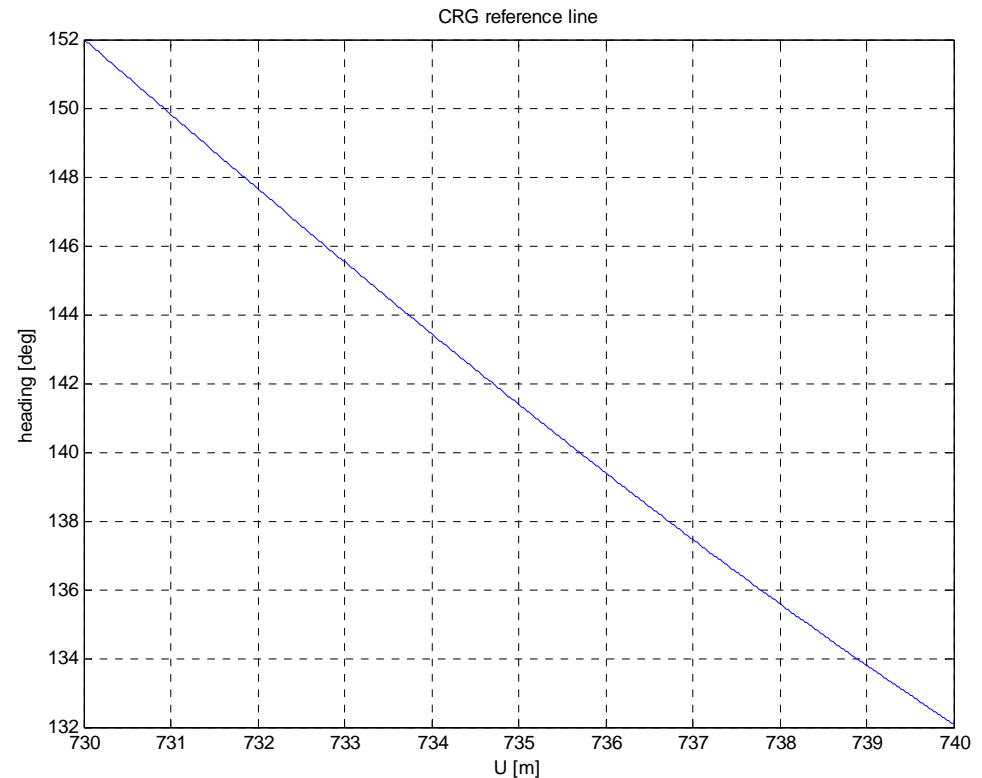
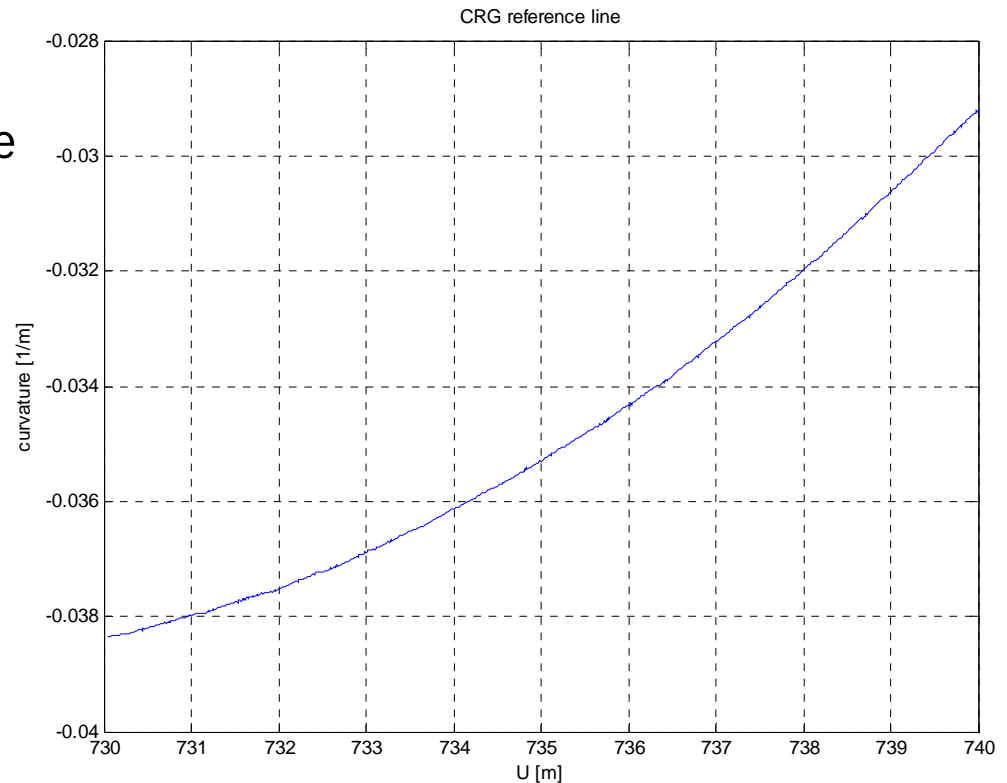CRG reference line

CRG (curved regular grid) Overview Demo

Figure 2 of: `crg_show(crg_read('../crg/demo_real.crg'))`

- The curvature of the reference line is starting with 0.04 m^{-1}, equivalent to a 25m radius.

- The curvature is smooth: this is very important for further use of the reference line for steering control

CRG (curved regular grid) Overview Demo
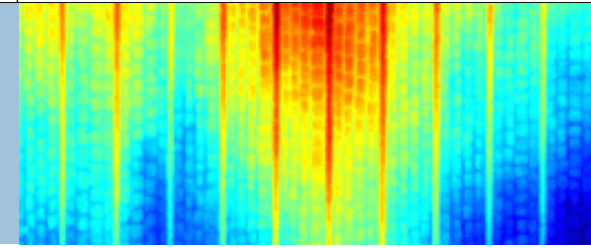
Figure 3 of: `crg_show(crg_read('../crg/demo_real.crg'))`

- This is the "map" view of the reference line (starting at the lower right edge)

CRG reference line
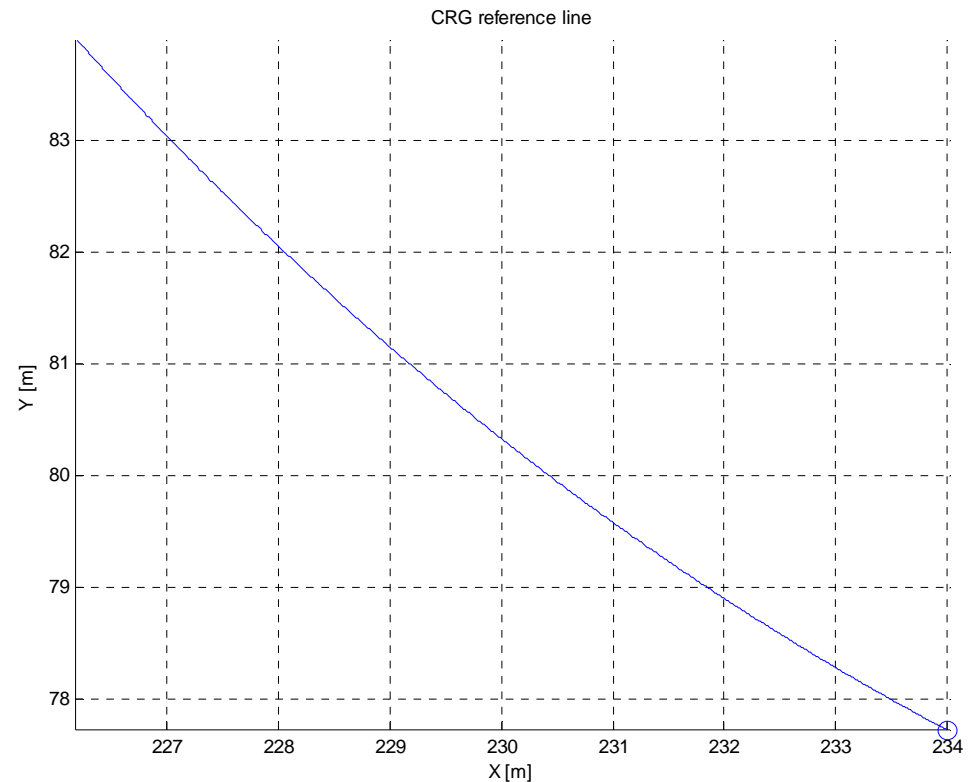
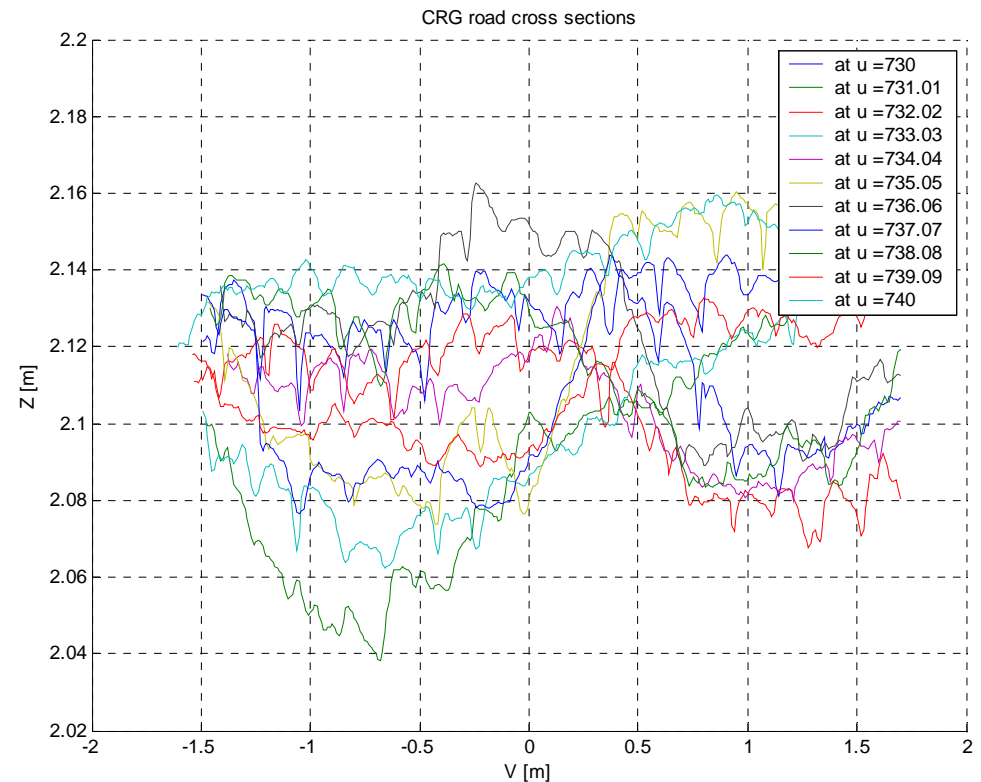# CRG (curved regular grid) Overview Demo

Figure 4 of: `crg_show(crg_read('../crg/demo_real.crg'))`

- Some cross sections.
  (yes – it's a rough road!)

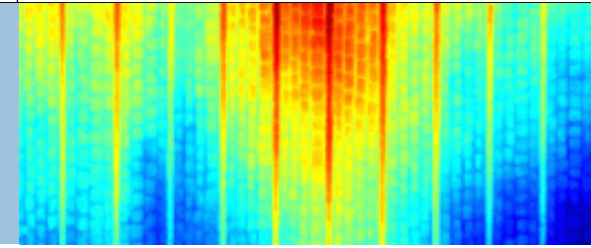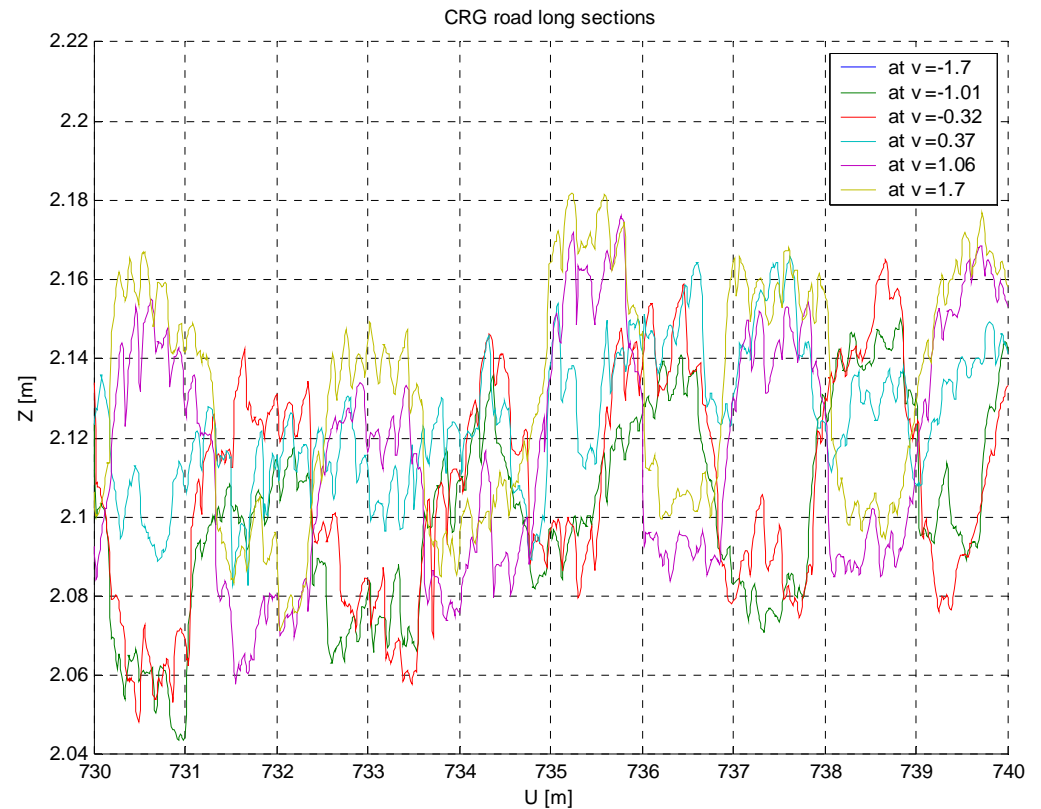# CRG (curved regular grid) Overview Demo

Figure 5 of: `crg_show(crg_read('../crg/demo_real.crg'))`

- Some long sections.

CRG road long sections

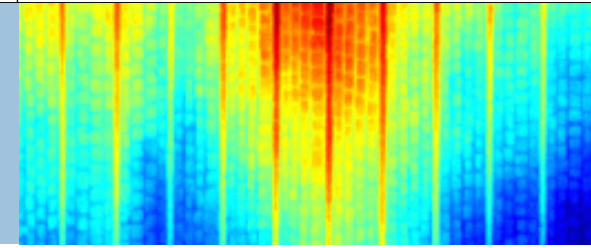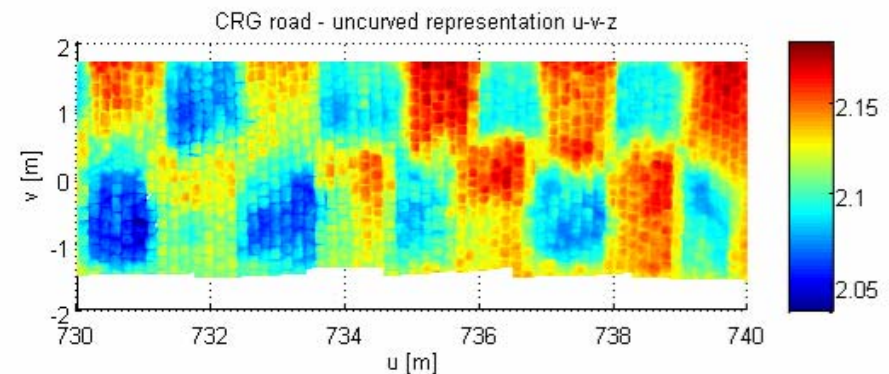# CRG (curved regular grid) Overview Demo

Figure 6 of: `crg_show(crg_read('../crg/demo_real.crg'))`

- This is the "straightened" curved road.

- Missing measurements are stored as NaNs
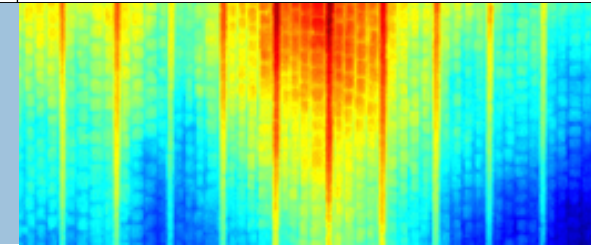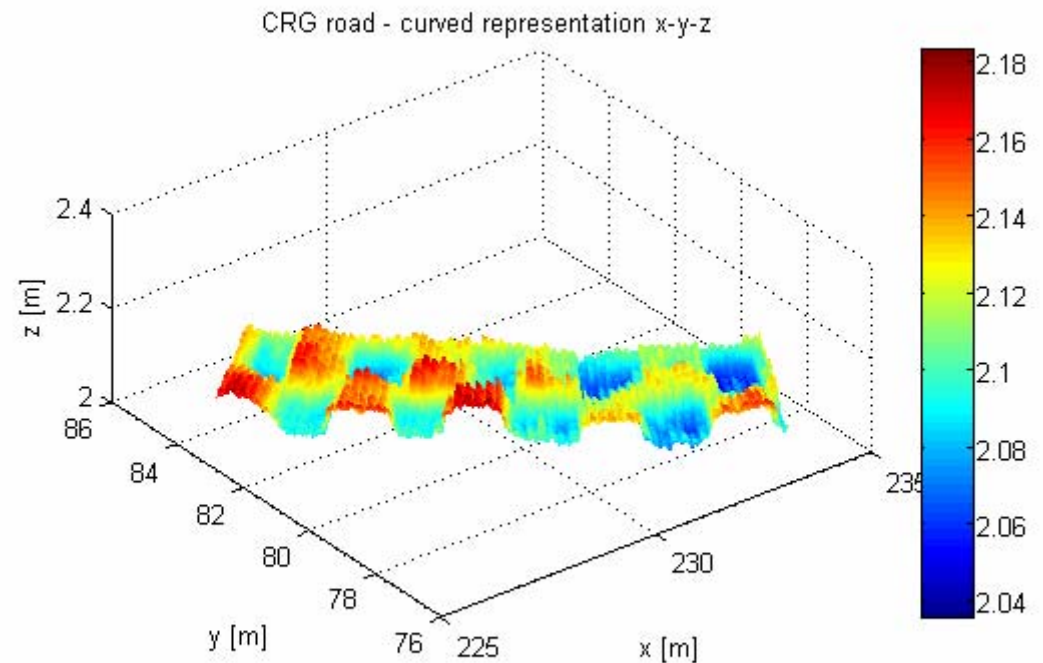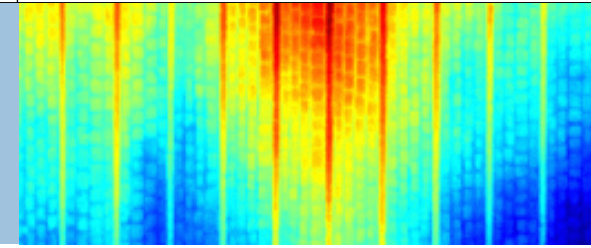
CRG (curved regular grid) Overview Demo

Figure 7 of: `crg_show(crg_read('../crg/demo_real.crg'))`

■ This is the "perfect" 3D reconstruction of the measured road.

CRG road - curved representation x-y-z

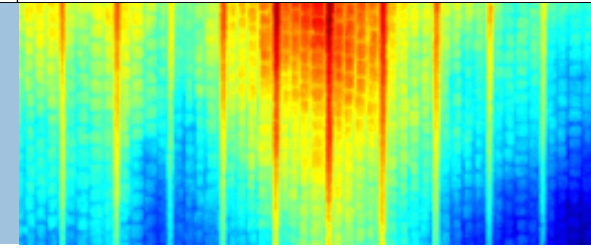# CRG (curved regular grid) Overview Evaluation Principle

Task: Get z(x, y)

- Rebuild reference line from heading information

- Find u value of reference line closest to (x, y)

- Calculate v value as normal distance of (x, y) to reference line

- Get z(u, v) by interpolation in regular grid

Main Challenge: Get (u, v) for given (x, y)

- CPU time efficient search strategy

- Deterministic convergence behavior

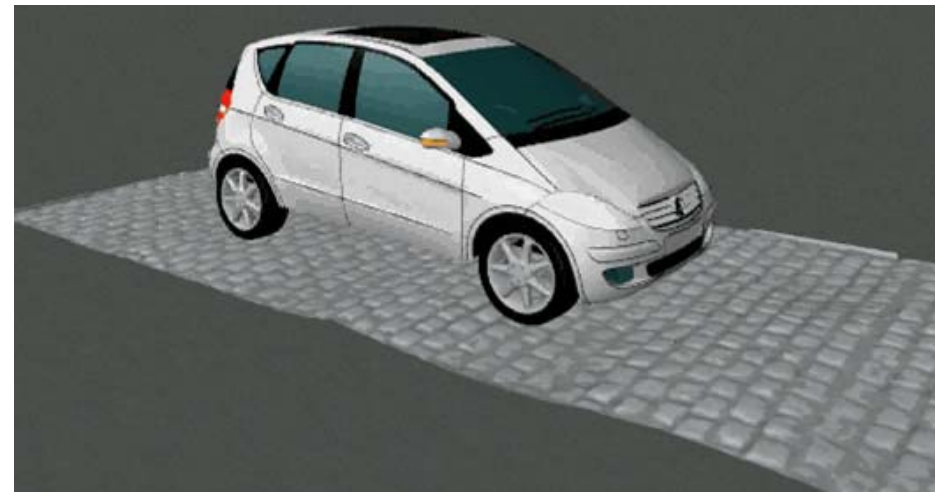# CRG (curved regular grid) Overview
Basic Usage at DaimlerChrysler

Internal API implementation (non-public – as application example)

Basic Methods:

- CARCRR(file): open/read CRG file
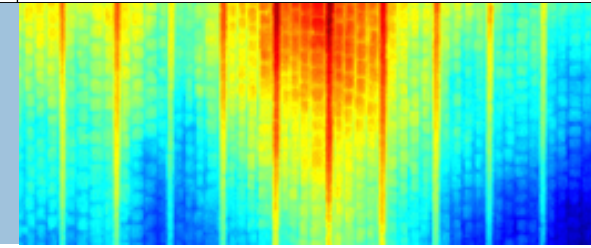
- CARCRZ(x,y, z): evaluate z(x,y)

Extensions:

- CARCRV(x,y, u,v): evaluate u(x,y), v(x,y)

- CARCRU(u,v, z): evaluate z(u, v)

- CARCRX(u,v, x,y): evaluate x(u, v), y(u,v)

Typical Performance on rough road tracks (for comparison to other implemantations)

- 2.5e-07 sec for one complete CARCRZ call on a 3GHz INTEL CPU

Summary / Perspectives

- Reliable road surface measurements are provided by commercial suppliers, e.g. TÜV SÜD Automotive GmbH.

- The introduced CRG road data format guarantees a simple, portable, storage and CPU-time efficient solution for further use of the measured data in simulation.

- Using the CRG road data format eliminates further preprocessing needs.

- The use of an unique CRG format eliminates needs for conversion between (even slightly) incompatible road surface descriptions and guarantees consistent and reliable road surface representations for simulation applications.

- By putting the CRG format and some Matlab demo implementations to the public DaimlerChrysler wants to motivate it's use and to initiate development of further useful tools e.g. for visualization, road data analysis, etc. Making these extensions available to the public would help the whole simulation community to focus on their primary tasks.

- For further comments, questions, and communication needs between CRG users, jochen.rauh@daimlerchrylser.com can be contacted.