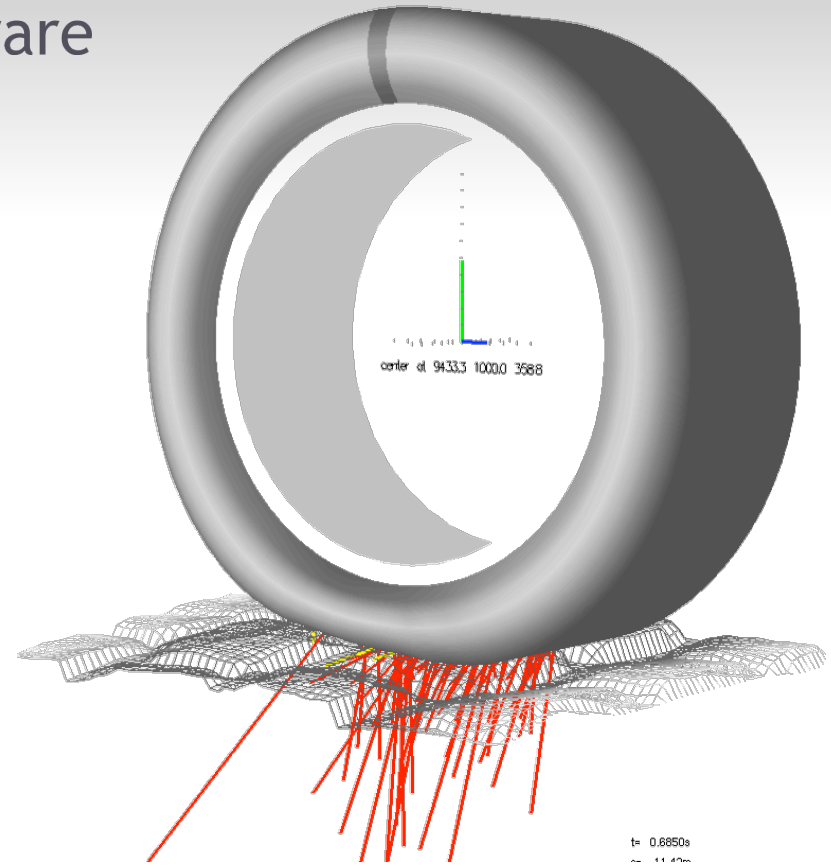
cosin
scientific software



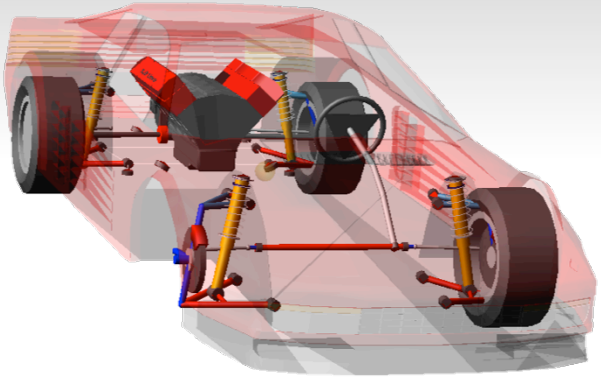
FTire: a Physically Based Tire Model for Handling, Ride, and Durability

Part 6: Road Models

Michael Gipser
Esslingen University of Applied Sciences
& cosin scientific software

cosin
scientific software

FTire
Vehicle - Tire - Road Interaction



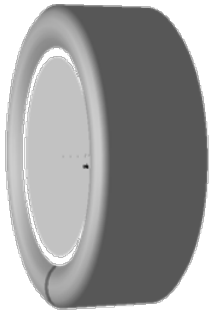
vehicle model calls

CTI

Cosin Tire Interface

rim position and velocity

spindle forces and moments



tire model

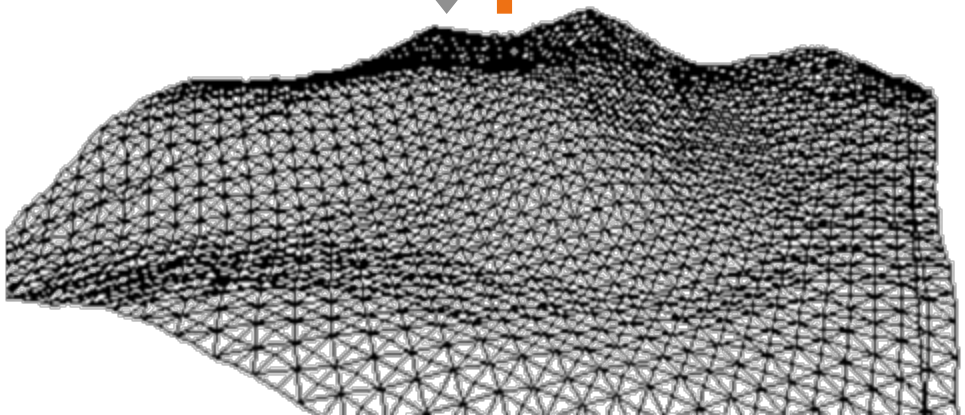
tire model calls

CRI

Cosin Road Interface

distributed contact forces

detailed surface geometry

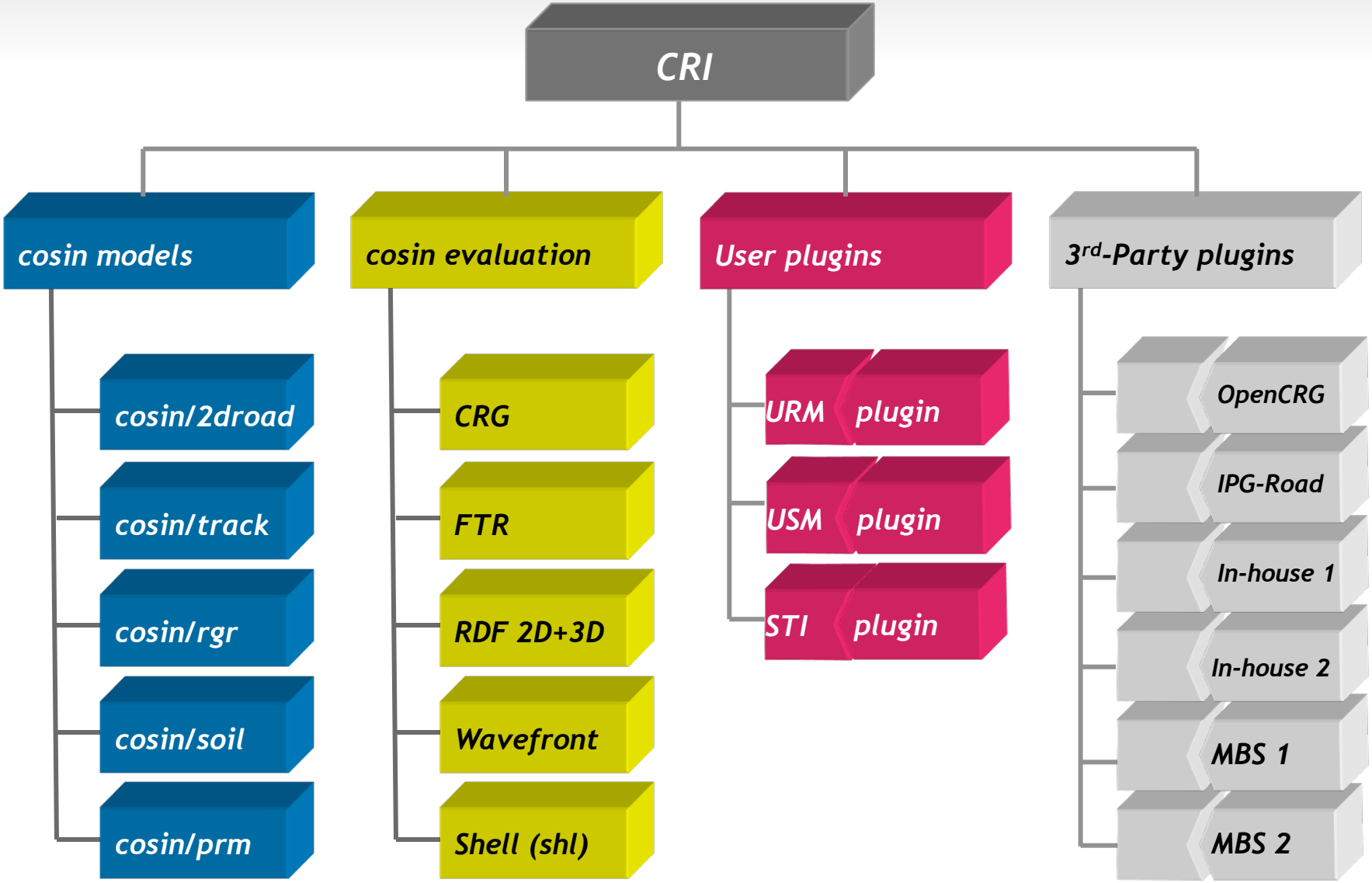


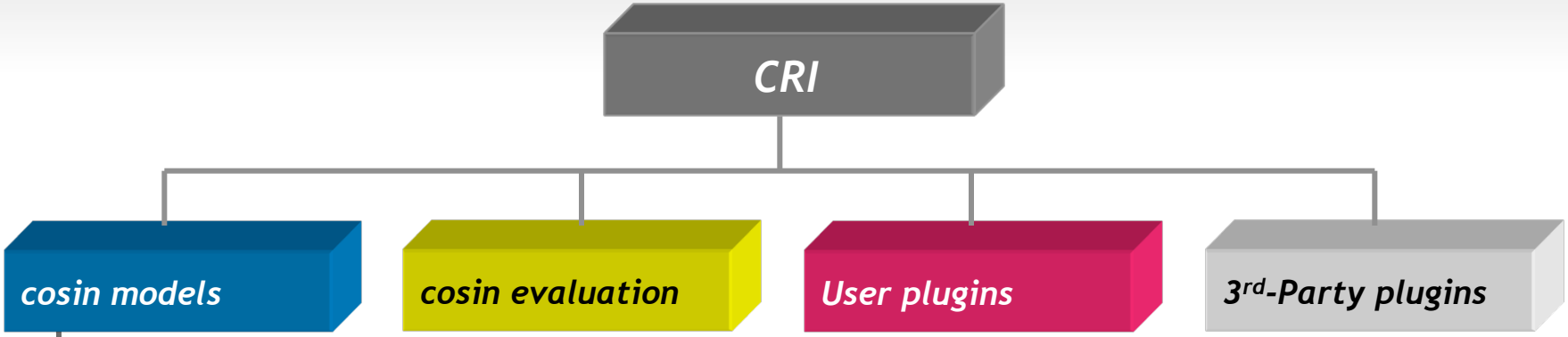
road/soil model

FTire: Supported Road Models

- all MSC.ADAMS rdf- and xml-files and all methods, including VI-SportsCar
- *cosin/ev* Road Models (cosin)
- RGR Roads (Regular Grid Road Files, cosin)
- CRG Roads (Daimler and Vires)
- FTR Roads (VI-grade)
- WaveFront triangulation files (.obj)
- Shell triangulation files (.shl)
- IPG-Road
- TYDEX/STI Standard Road Description Format
- URM (Program Interface to User-Defined Road Models)
- USM (Program Interface to User-Defined Soft-Soil Models)
- several user-specific proprietary models

CRI: FTire's Gateway to Road Models and Interfaces





cosin/2droad

analytical **2D and 3D rigid road surface description**: single obstacles, rotating drum with cleats, hydro-pulse, stochastically uneven roads ..

cosin/track

analytical **road center line description** (RAS-L line elements): straight line, clothoid, circle, banking angle, lane number, lane widths, animation data ..

cosin/rgr

Cosin Regular Grid Roads: efficient storage, evaluation and analysis of high resolution road surfaces, including OpenCL-accelerated implementations

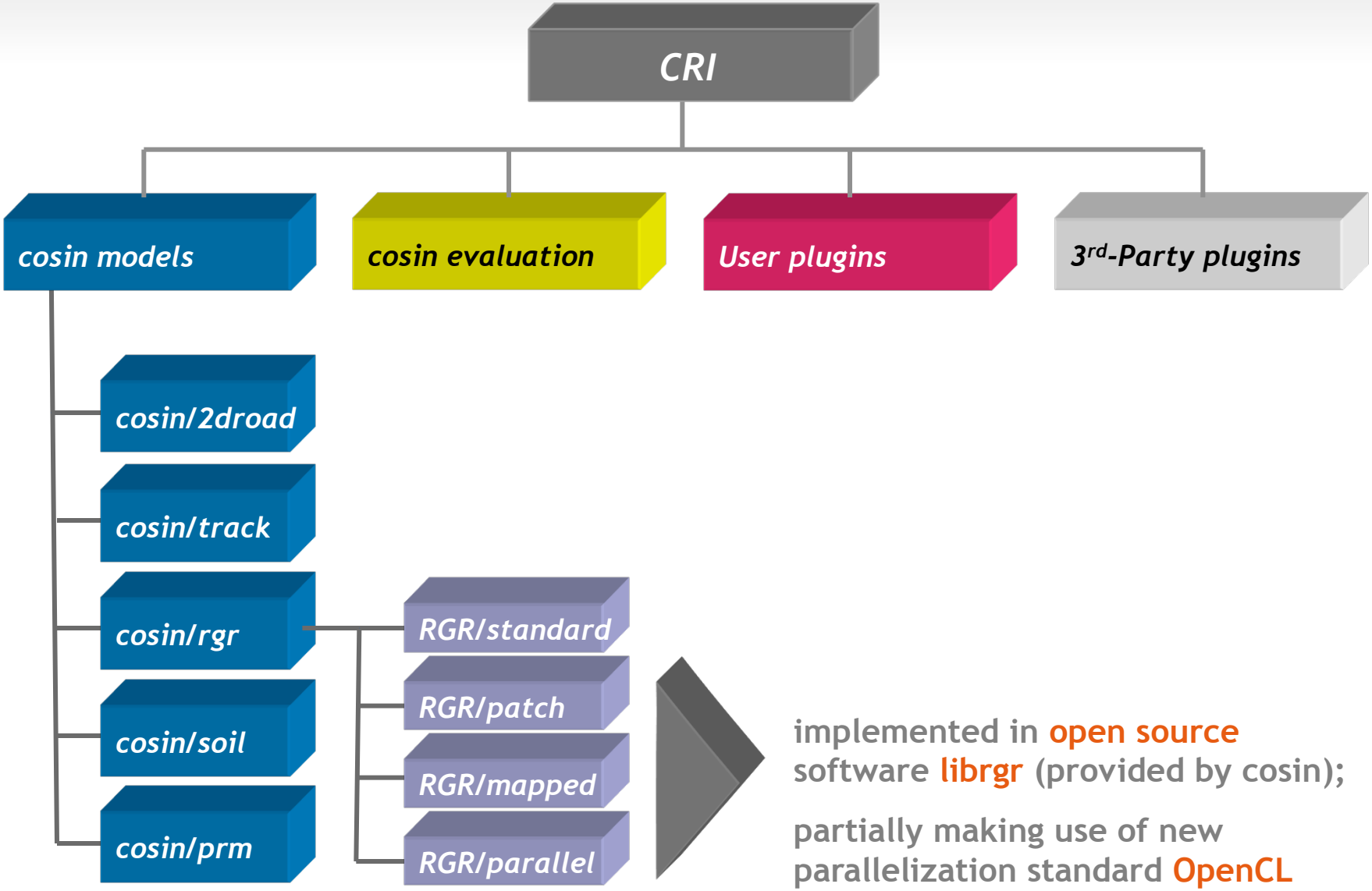
cosin/soil

Cosin Soft Soil Model: cosin's internal or user-defined soft soil model

cosin/prm

Cosin Particle Road Model: cosin's granular material road surface model, making use of massively parallel GPU computations. *Under development*

FTire
Cosin Regular Grid Road Implementations



implemented in open source software librgr (provided by cosin);

partially making use of new parallelization standard OpenCL

in..

TI	tire index
T,X,Y	simulation time and position in x-y-plane

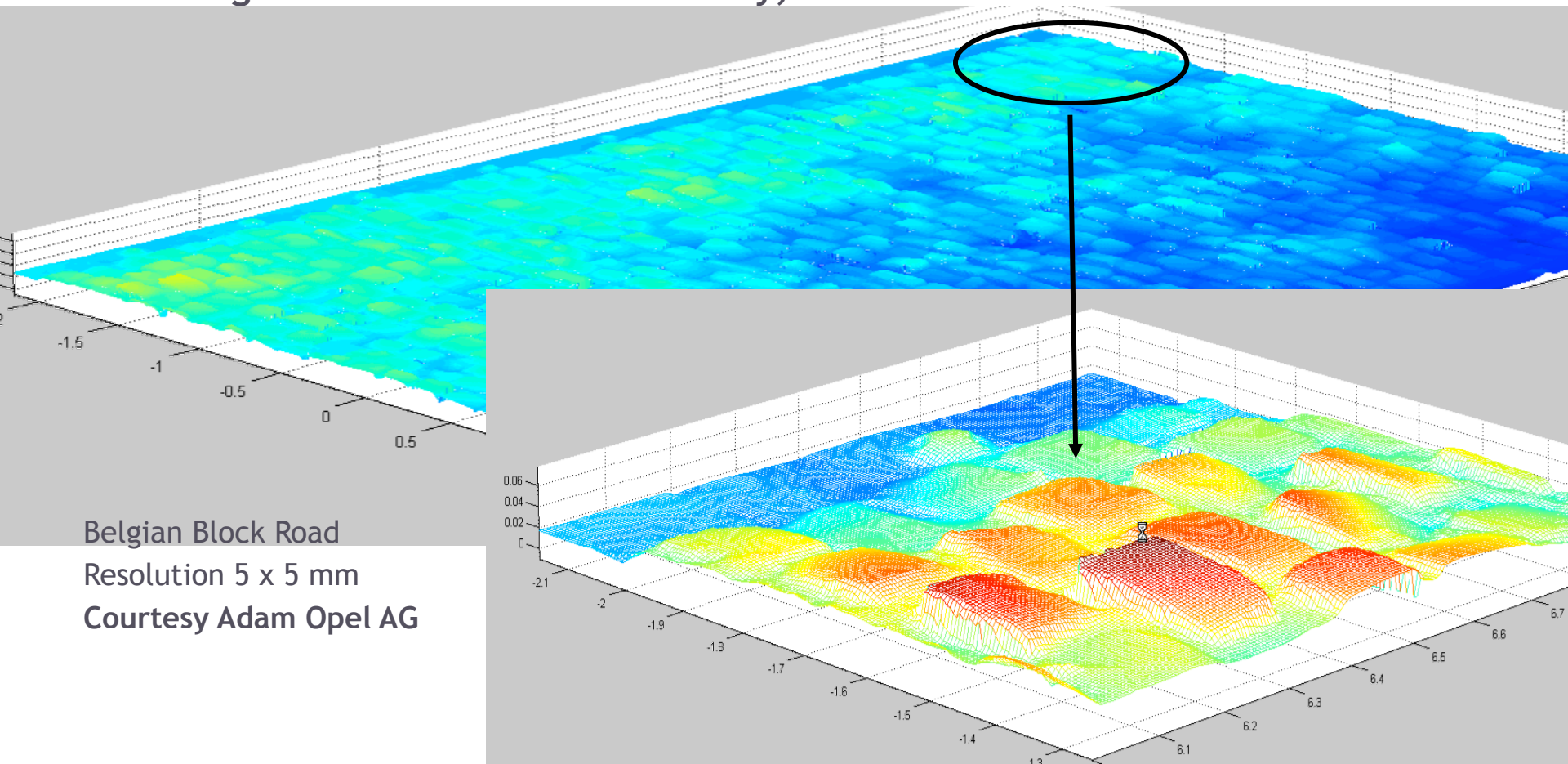
```
CALL URM ( TI,FILE, T,X,Y,   Z, VX,VY,VZ, MU, IER )
```

..out

Z	road height at time t and position x/y
VX,VY,VZ	inertial velocity of point x/y/z
MU	friction modification factor at time t and position x/y
IER	error return code. 0, if computation is ok

Rapid evaluation of high-resolution measured road surfaces with Regular Grid road data files

no filtering or data reduction necessary;

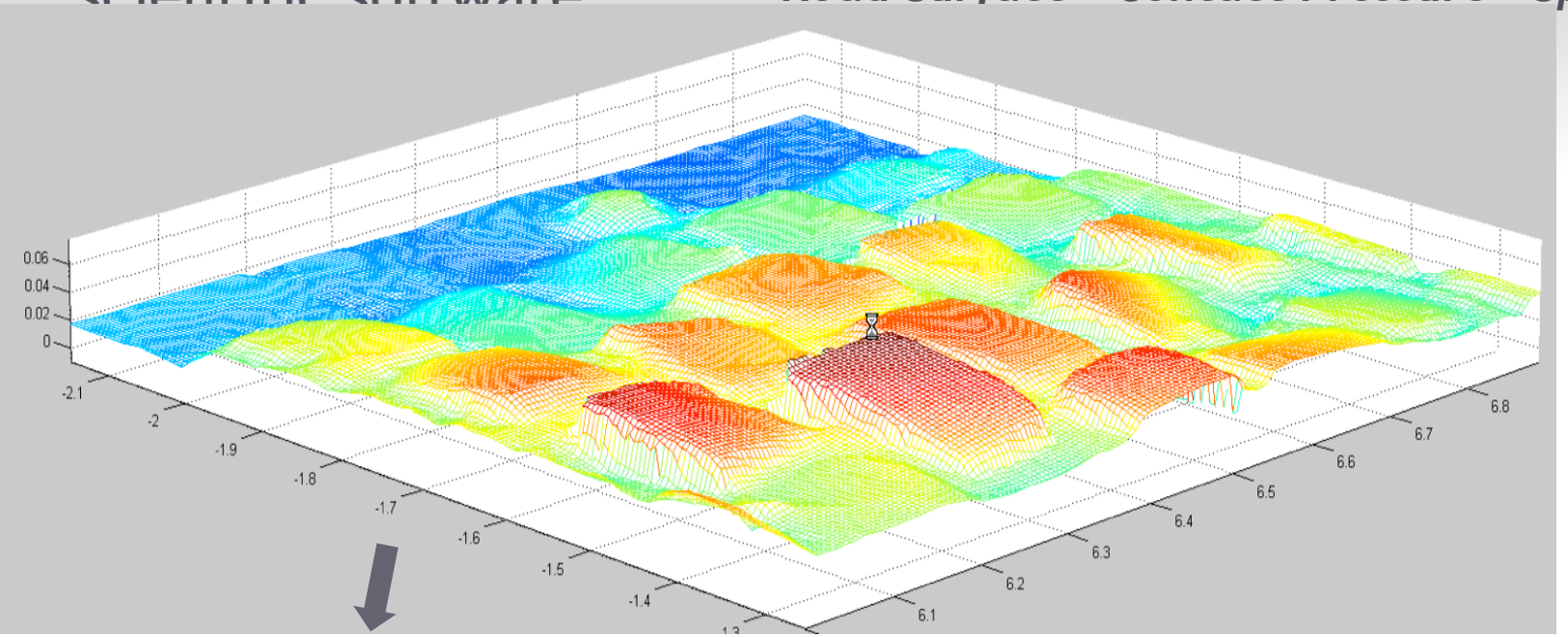


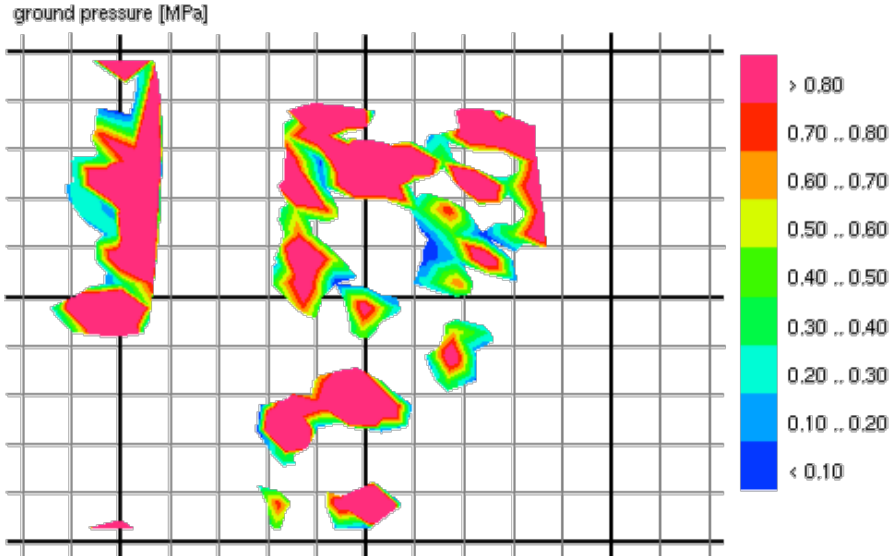
Belgian Block Road
Resolution 5 x 5 mm
Courtesy Adam Opel AG

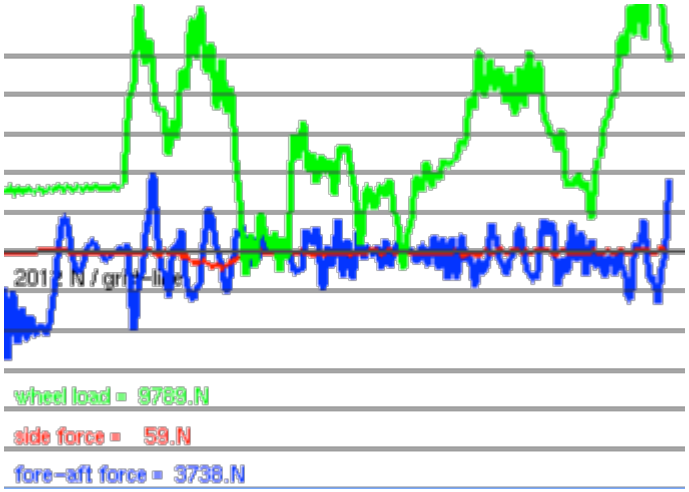
RGR Road Data Files

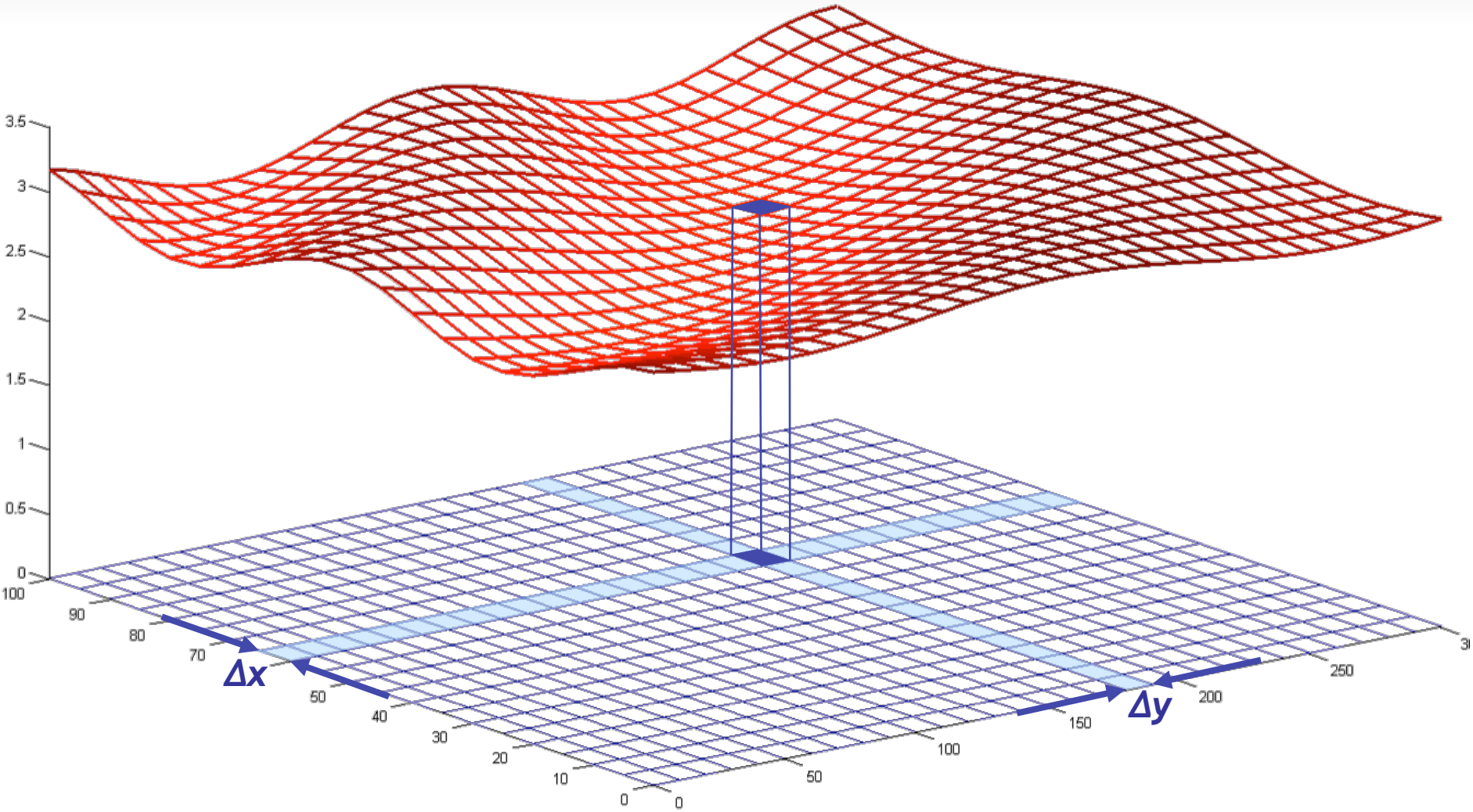
- are evaluated with highest efficiency and accuracy
  no search for active triangles
- are available both in ASCII and platform-independent binary format
- have lossless compression
- are rapidly loaded, even if files are huge
- may have a curvilinear center line, to follow road courses
- can export center line for driver models
- can export shl files for road display in ADAMS/PPT
- can be split into dynamically loadable patches

FTire
Road Surface - Contact Pressure - Spindle Loads









RGR idea: **equidistant mesh avoids search of active triangle**

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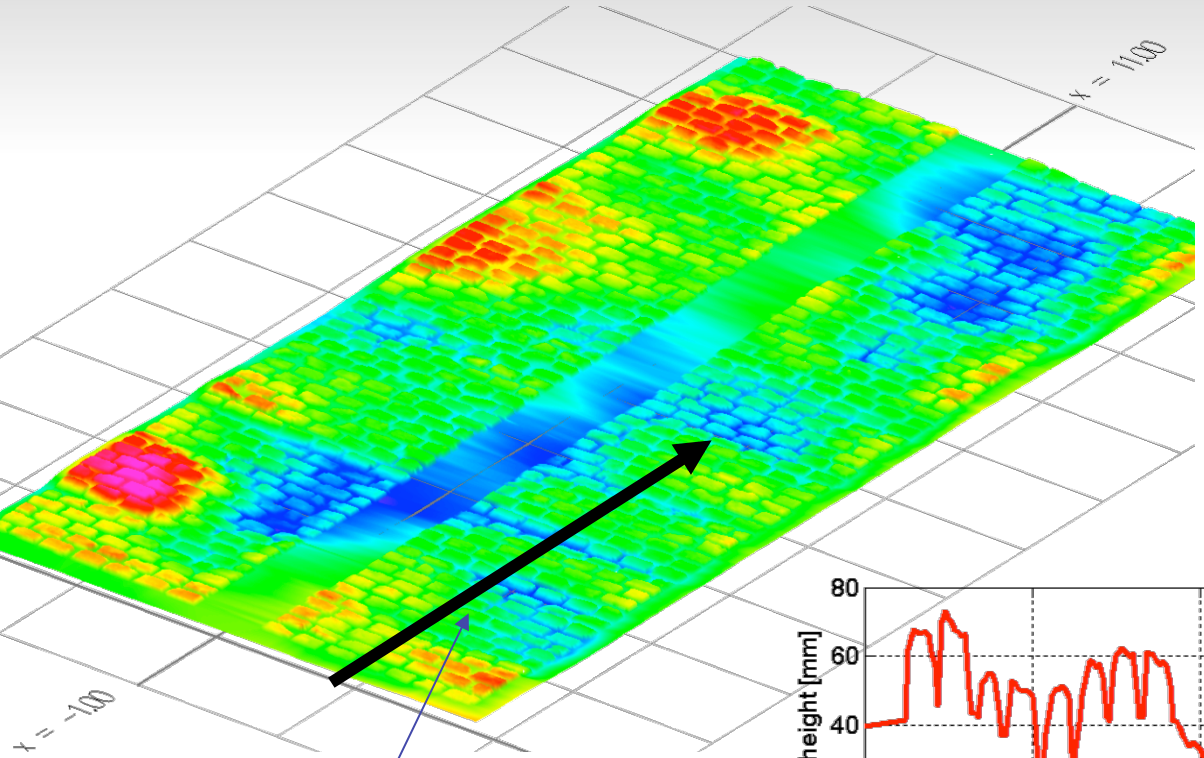
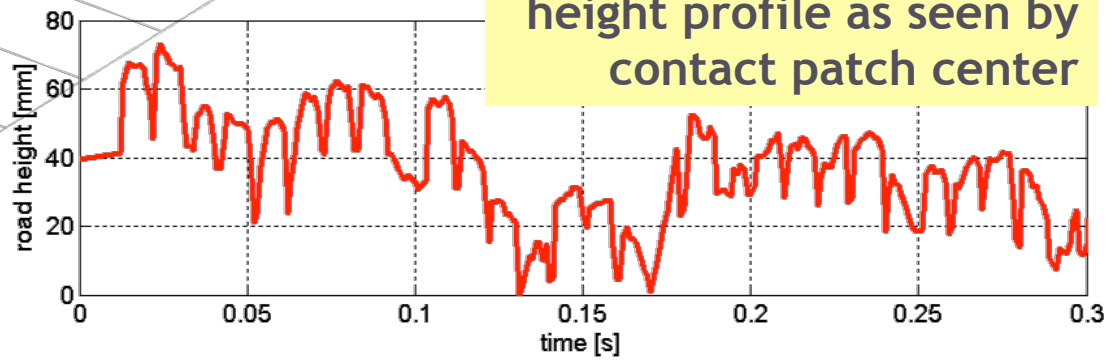
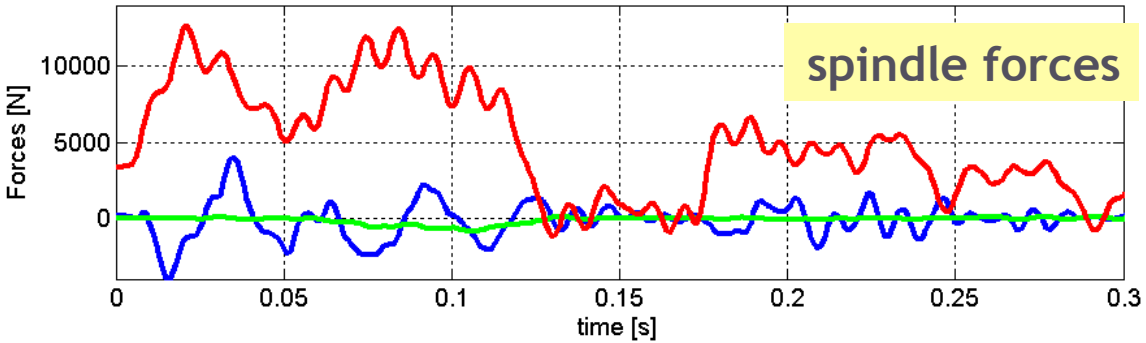
FTire
Road Loads on Belgian Block



traveled path

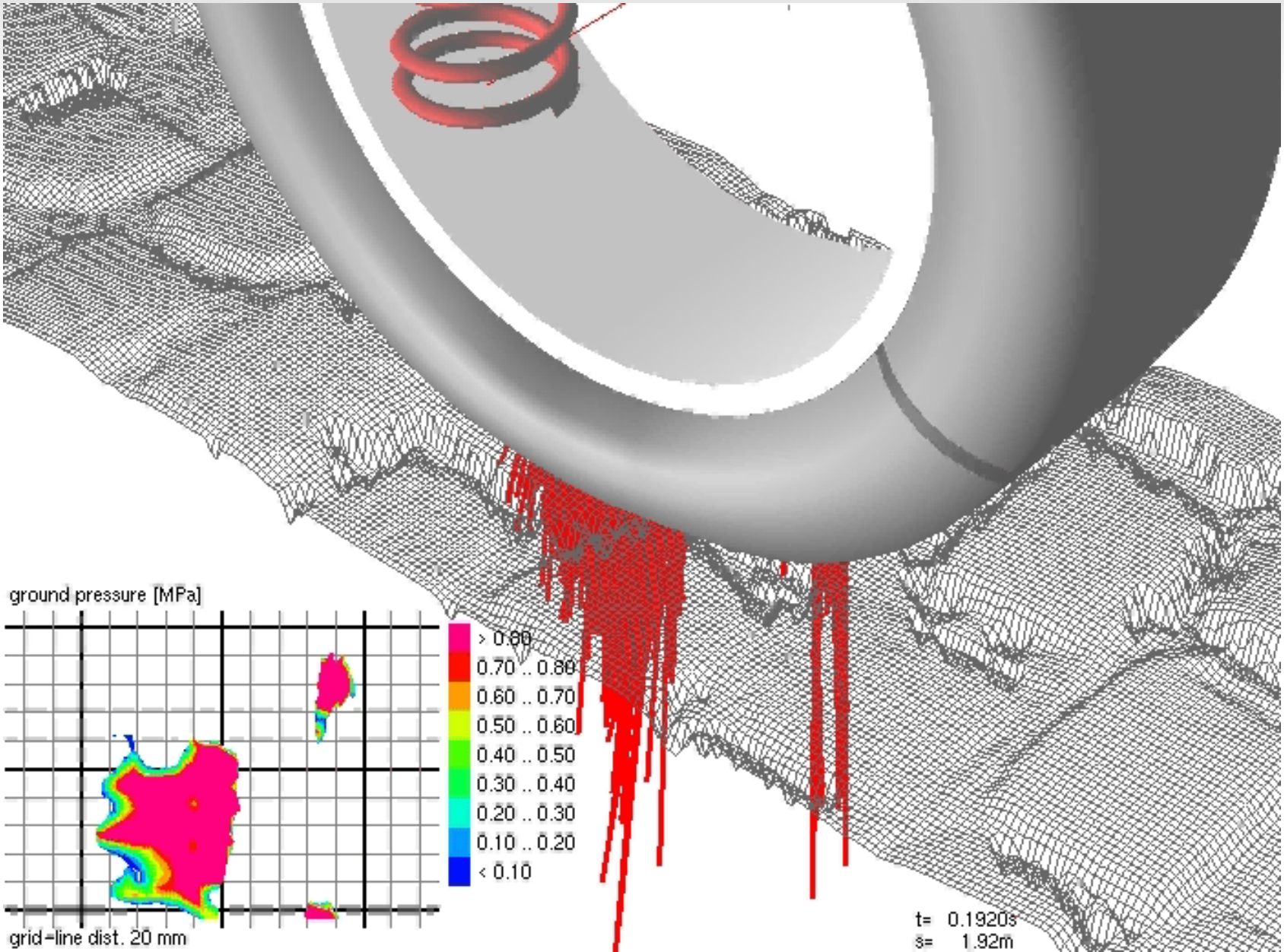


height profile as seen by contact patch center



spindle forces

FTire
Road Surface – Contact Pressure – Spindle Loads



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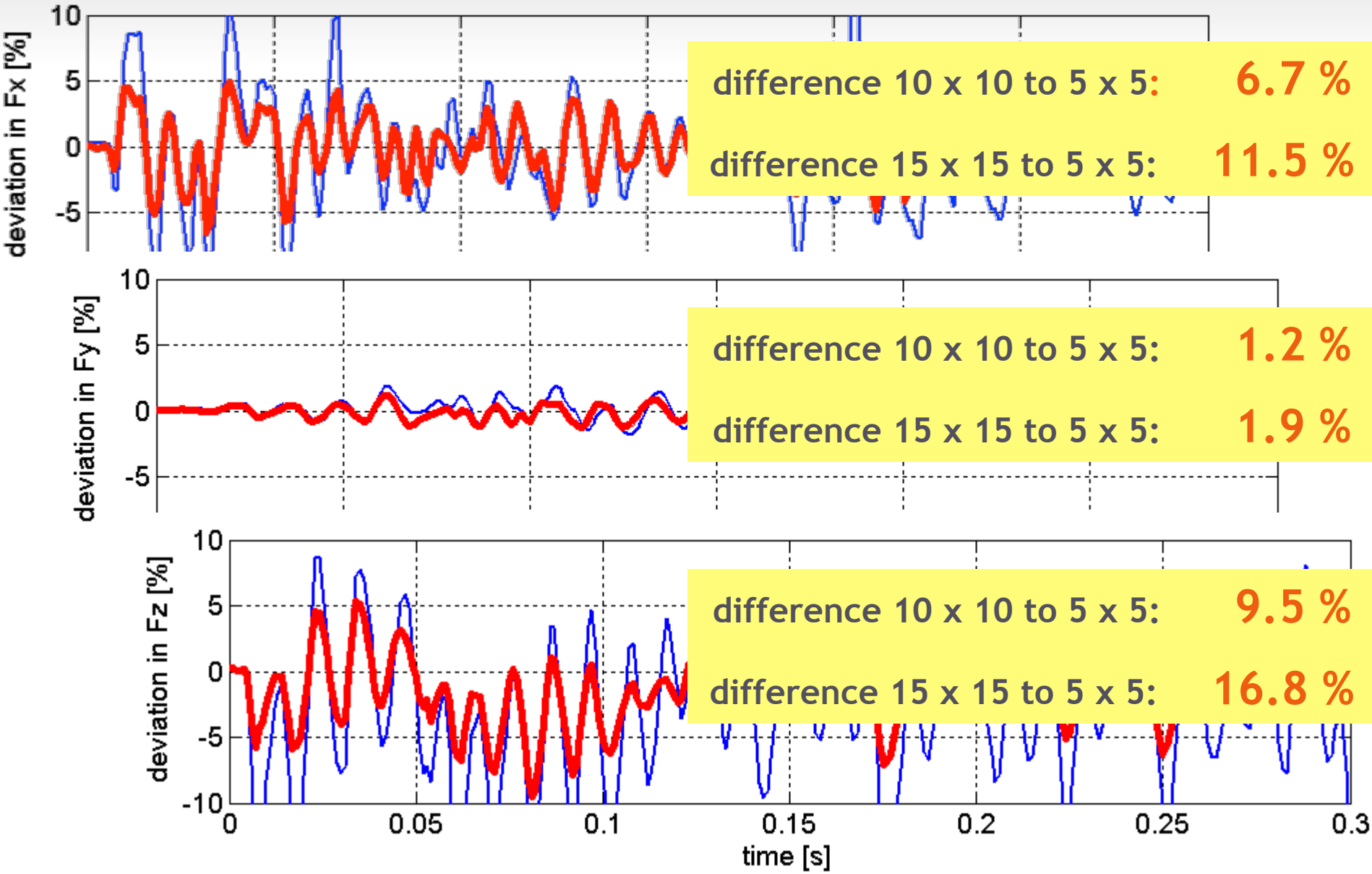
FTire

Road Resolution: Impact on Predicted Road Loads

red: 10x10 vs. 5x5 mm blue: 15x15 vs. 5x5 mm



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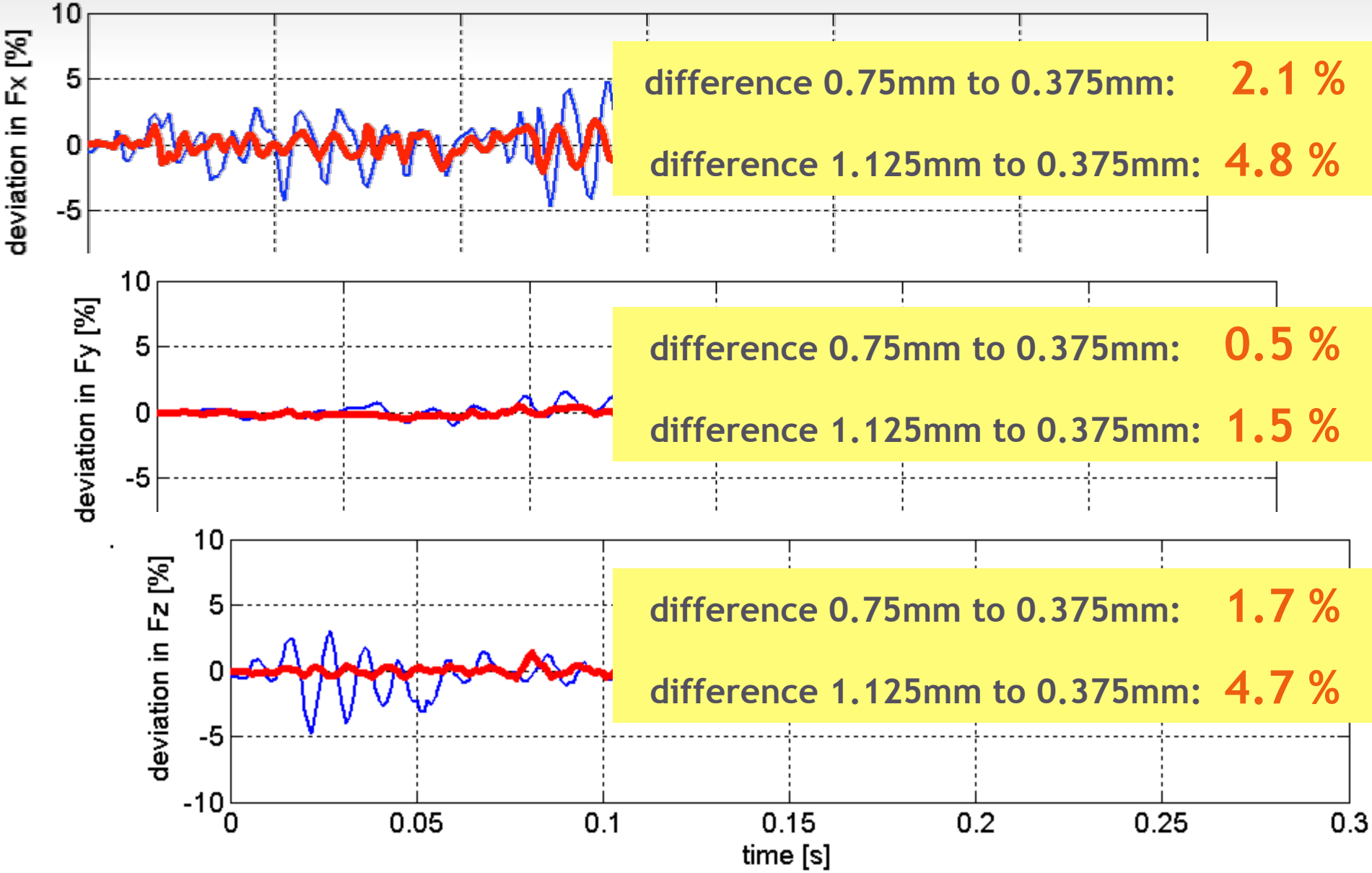
scientific software

FTire

Tread Resolution: Impact on Predicted Road Loads

red: 0.75 mm vs. 0.375 mm blue: 1.125 mm vs. 0.375 mm



Efficiency Comparison for Belgian Block Road File Formats

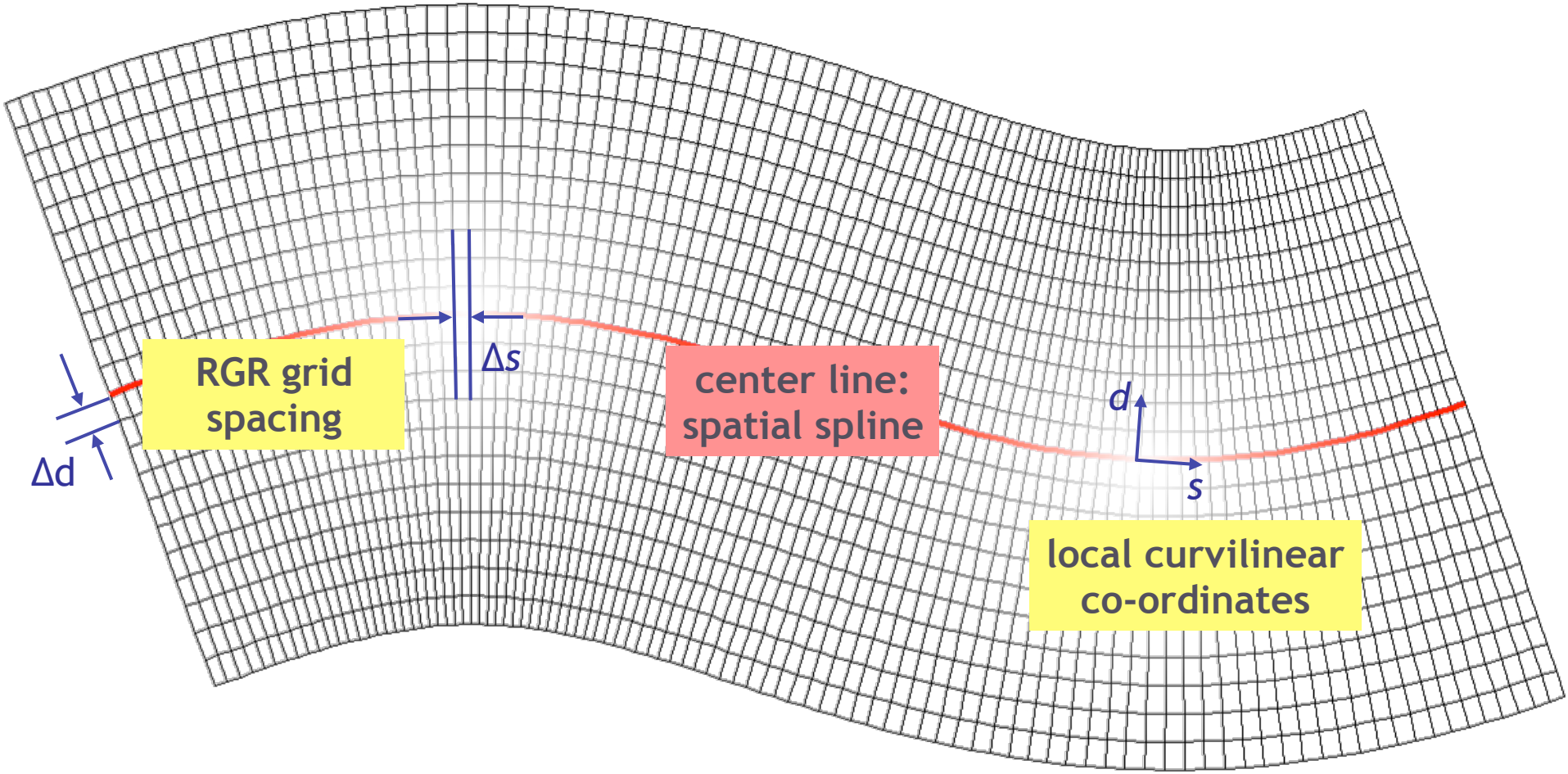
	Triangulated Road 3D TeimOrbit	RGR ASCII data file	RGR binary data file	RGR binary data file + curved center line
nodes	1 486 743	1 486 743	1 486 743	1 486 743
triangles	2 968 000	-	-	-
file size	153.74 MB	12.88 MB	5.80 MB	6.02 MB
memory amount	237.80 MB	5.80 MB	5.80 MB	5.91 MB
file loading time	95.75 s	0.73 s	0.21 s	0.28 s

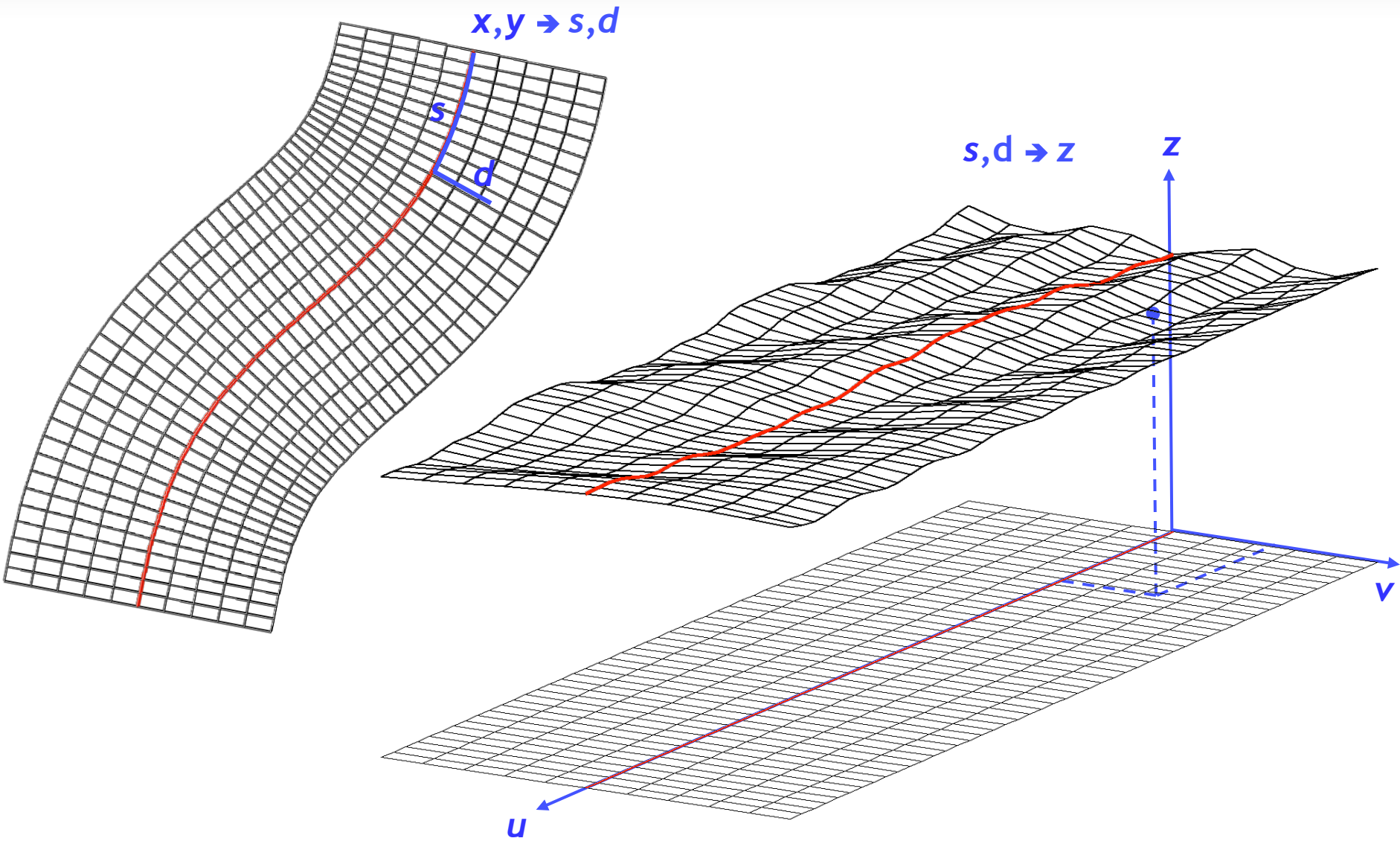
CPU Time for 1 Mio Road Evaluations

mean evaluation point distance	Triangulated Road 3D TeimOrbit	RGR ASCII data file	RGR binary data file	RGR binary data file + curved center line
0.001mm	0.826 s	0.203 s	0.203 s	0.556 s
0.01mm	0.984 s	0.203 s	0.203 s	0.556 s
0.1mm	2.98 s	0.203 s	0.203 s	0.556 s
1mm	23.2 s	0.203 s	0.203 s	0.556 s
10mm	222 s	0.203 s	0.203 s	0.556 s

CPU Time for 1s Simulation on Belgian Block Road

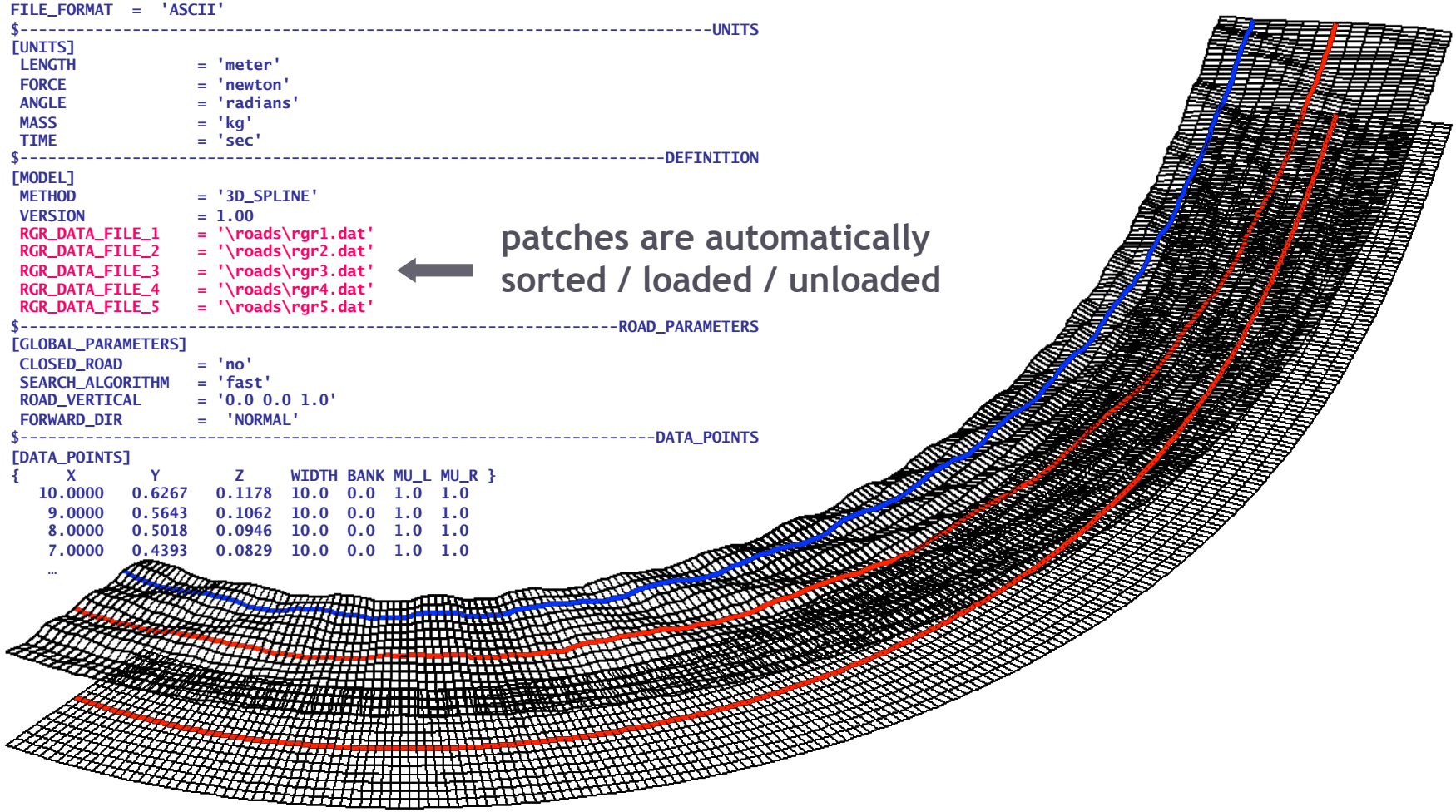
tread blocks per segment	total number of tread blocks	road evaluations per s	total CPU time per s with RGR road	total CPU time per s with TRIA road
20	1600	4.15 mio	6.8 s	551.0 s
30	2400	5.80 mio	7.9 s	564.0 s
40	3200	7.45 mio	8.9 s	567.0 s
50	4000	9.11 mio	10.1 s	574.0 s
60	4800	10.76 mio	11.3 s	576.0 s


RGR grid spacing
Δs
Δd
center line: spatial spline
d
s
local curvilinear co-ordinates


x,y → s,d
s
d
s,d → z
z
v
u

```
$-----------------------------------------------------------------------MDI_HEADER
[MDI_HEADER]
FILE_TYPE   =  'rdf'
FILE_VERSION  =  5.00
FILE_FORMAT  =  'ASCII'
$-------------------------------------------------------------------------------UNITS
[UNITS]
 LENGTH              = 'meter'
 FORCE               = 'newton'
 ANGLE               = 'radians'
 MASS                = 'kg'
 TIME                = 'sec'
$-----------------------------------------------------------------------DEFINITION
[MODEL]
 METHOD              = '3D_SPLINE'
 VERSION             = 1.00
 RGR_DATA_FILE_1     = '\roads\rgr1.dat'
 RGR_DATA_FILE_2     = '\roads\rgr2.dat'
 RGR_DATA_FILE_3     = '\roads\rgr3.dat'
 RGR_DATA_FILE_4     = '\roads\rgr4.dat'
 RGR_DATA_FILE_5     = '\roads\rgr5.dat'
$---------------------------------------------------------------------ROAD_PARAMETERS
[GLOBAL_PARAMETERS]
 CLOSED_ROAD         = 'no'
 SEARCH_ALGORITHM    = 'fast'
 ROAD_VERTICAL       = '0.0 0.0 1.0'
 FORWARD_DIR         =  'NORMAL'
$-----------------------------------------------------------------------DATA_POINTS
[DATA_POINTS]
{     X        Y        Z     WIDTH BANK MU_L MU_R }
   10.0000   0.6267   0.1178  10.0  0.0  1.0  1.0
    9.0000   0.5643   0.1062  10.0  0.0  1.0  1.0
    8.0000   0.5018   0.0946  10.0  0.0  1.0  1.0
    7.0000   0.4393   0.0829  10.0  0.0  1.0  1.0
    …
```

patches are automatically sorted / loaded / unloaded

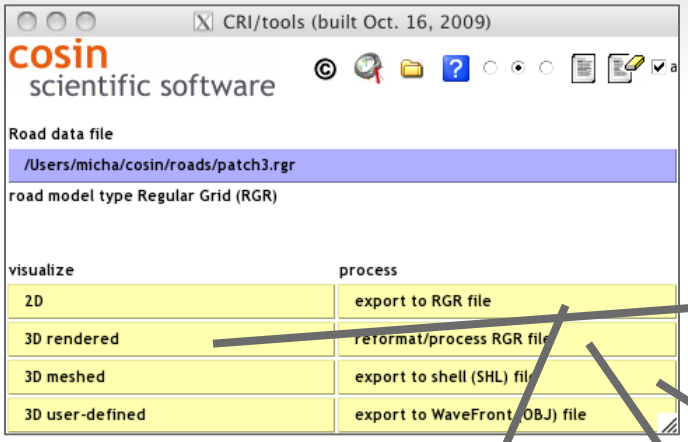


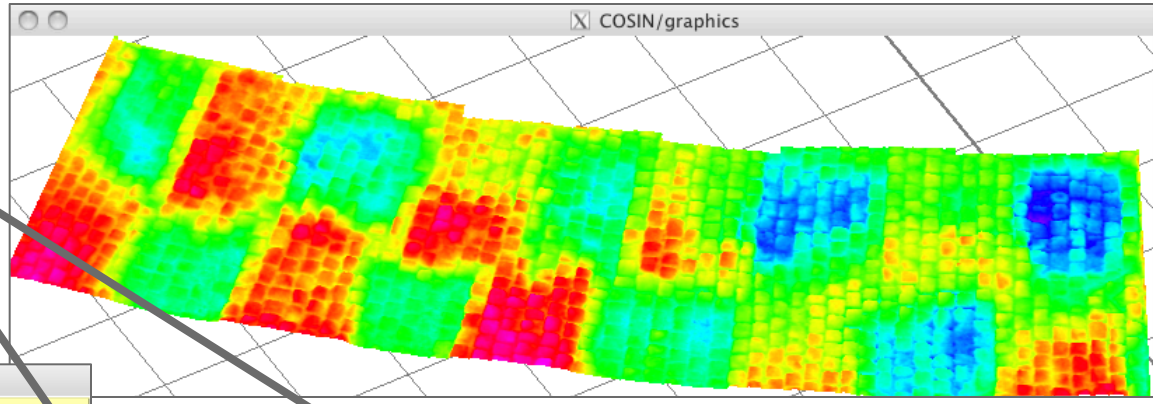
CRI/tools

- 2d visualization (single tracks)
- 3d visualization, meshed or rendered
- lossless format conversion CRG ➔ RGR + RDF
- generation of RGR roads out of any other supported road model
- generation of RGR roads out of 2D spectral density formula expression
- generation of RGR roads out of *z=f(x,y)* formula expression
- generation of RGR roads out of image data
- processing of RGR roads:
  - smoothing, compression, coarsening, filtering
  - ASCII ➔ binary, binary ➔ ASCII
  - splitting into patches
- generation of shl-files for road graphics in calling solver

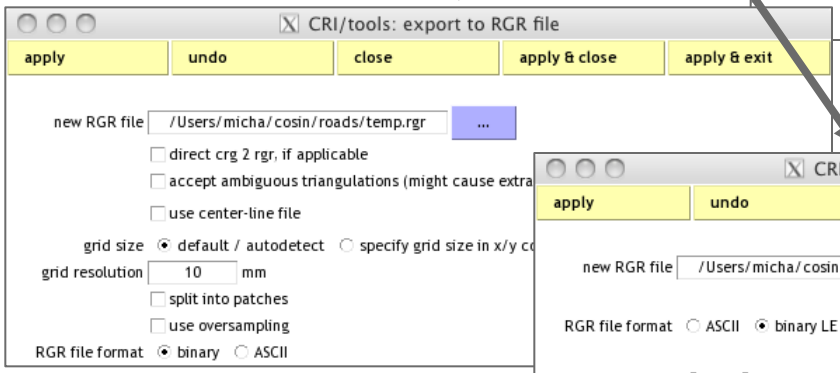
cosin
scientific software

FTire
CRI/tools

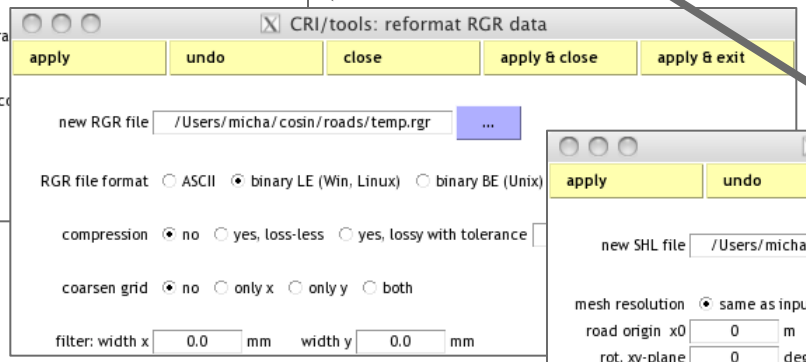




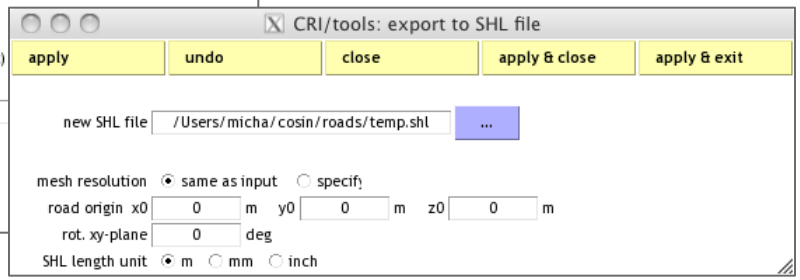
2D and 3D visualization



RGR file generation



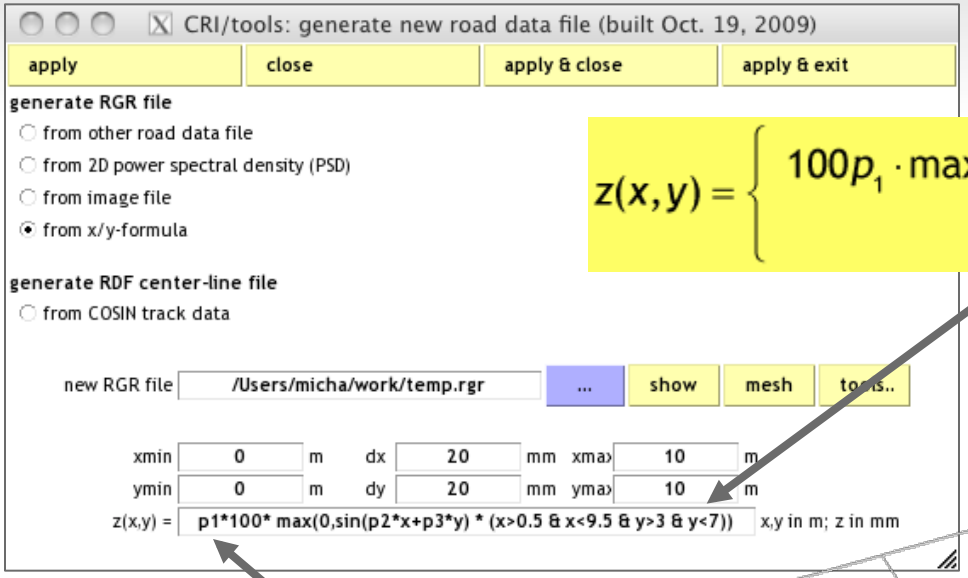
RGR file processing

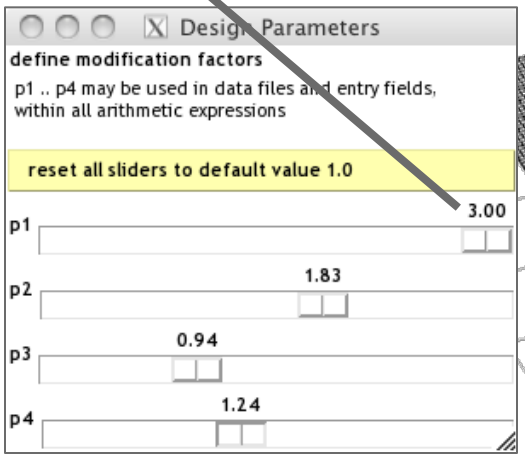


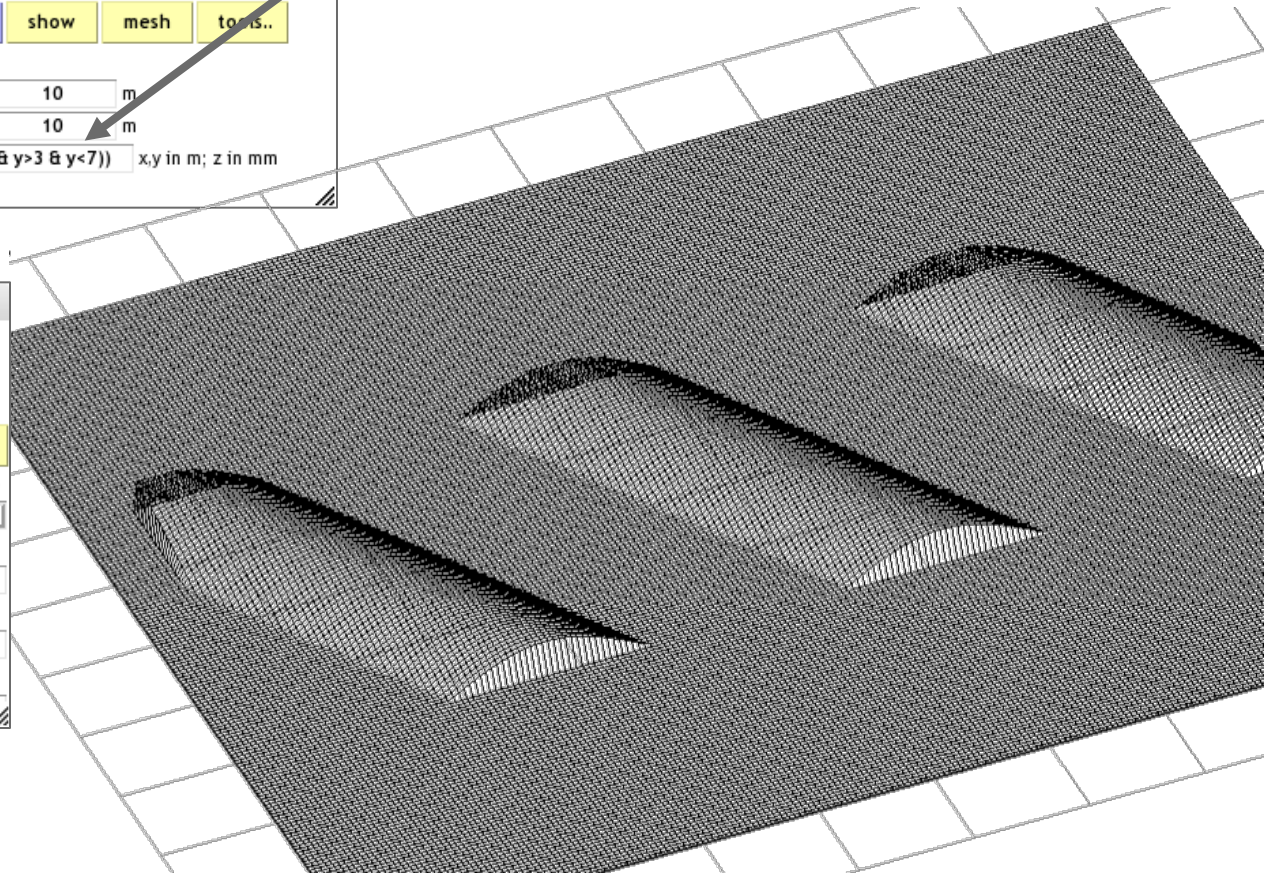
SHL and WaveFront file generation

arithmetic expression $z = f(x,y)$

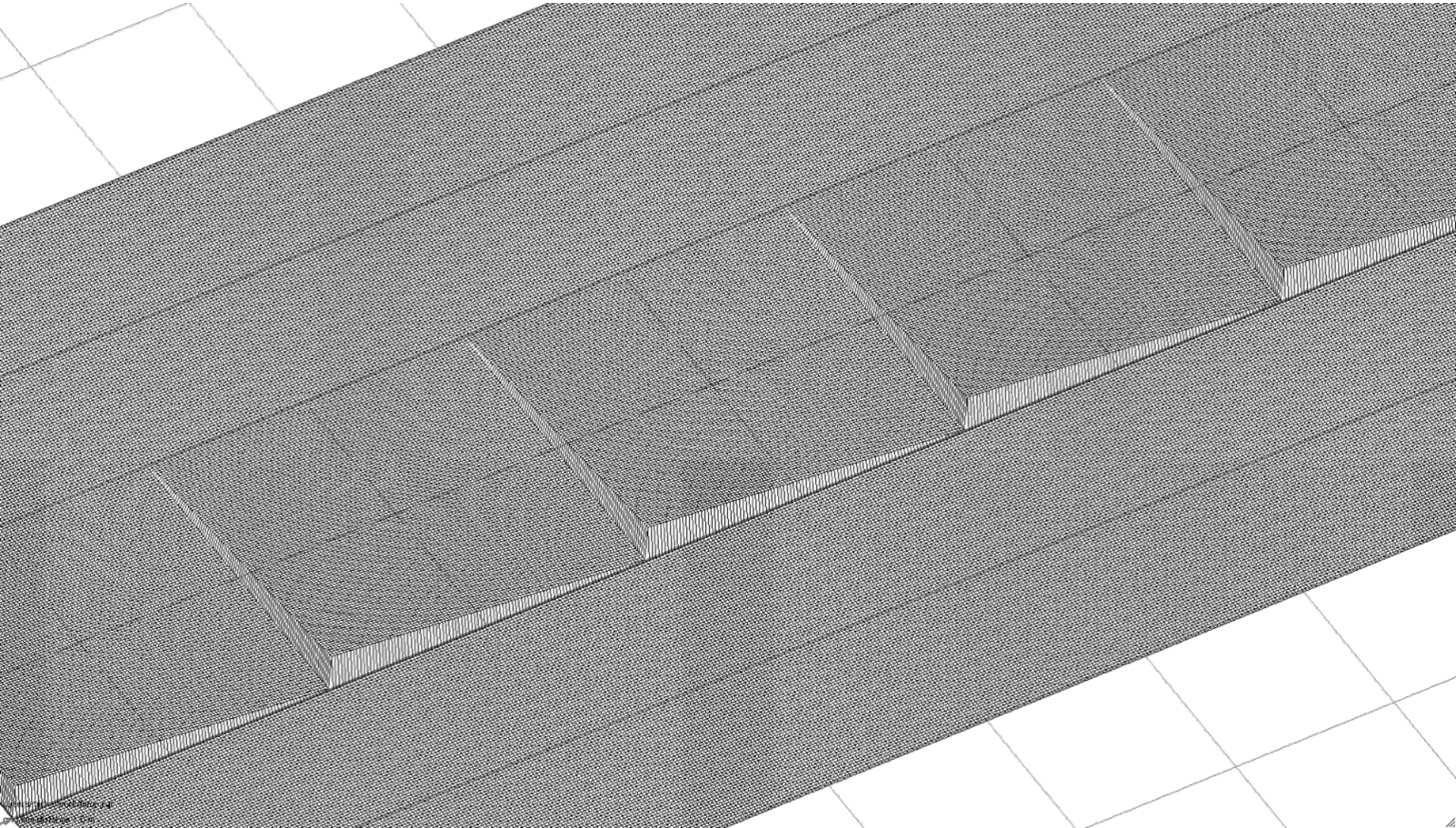
$$z(x,y) = \begin{cases} 100p_1 \cdot \max\left(0, \sin(p_2 x + p_3 y)\right) & \text{if} \quad (x,y) \in (0.5,9.5) \times (3,7) \\ 0 & \text{else} \end{cases}$$

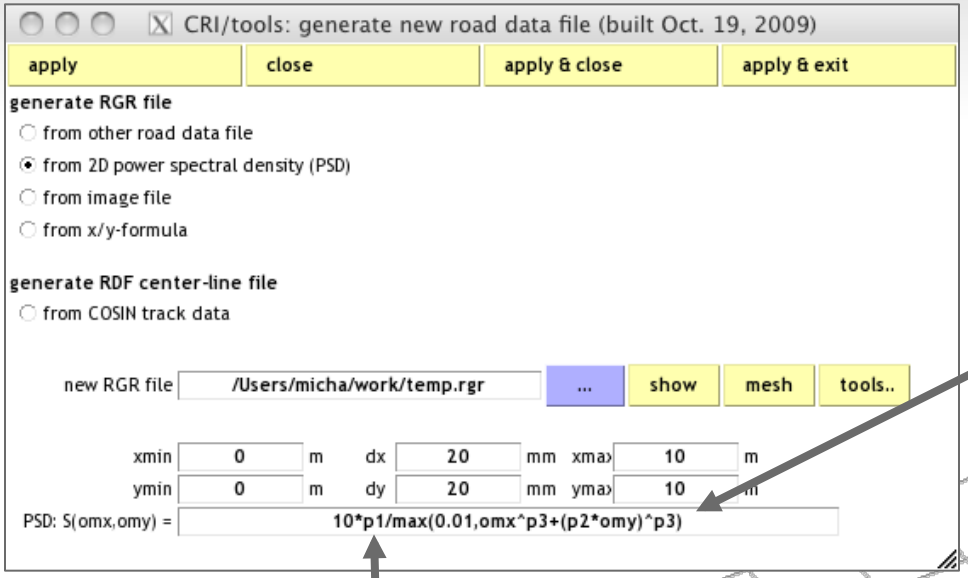






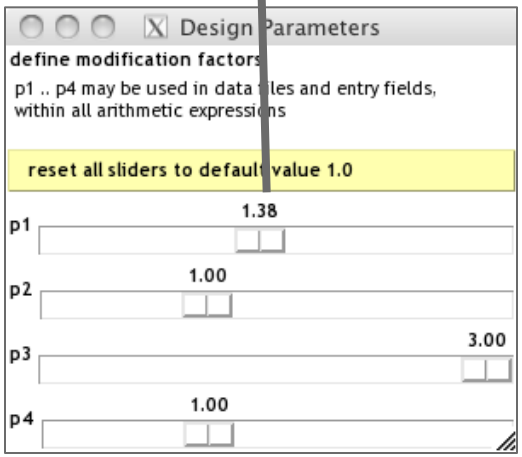
curbs: $z(x,y) = 100 \cdot p_1 \cdot (y > 0 \,\&\, y < p_2) \cdot \mathrm{mod}(x, p_2) \cdot y$

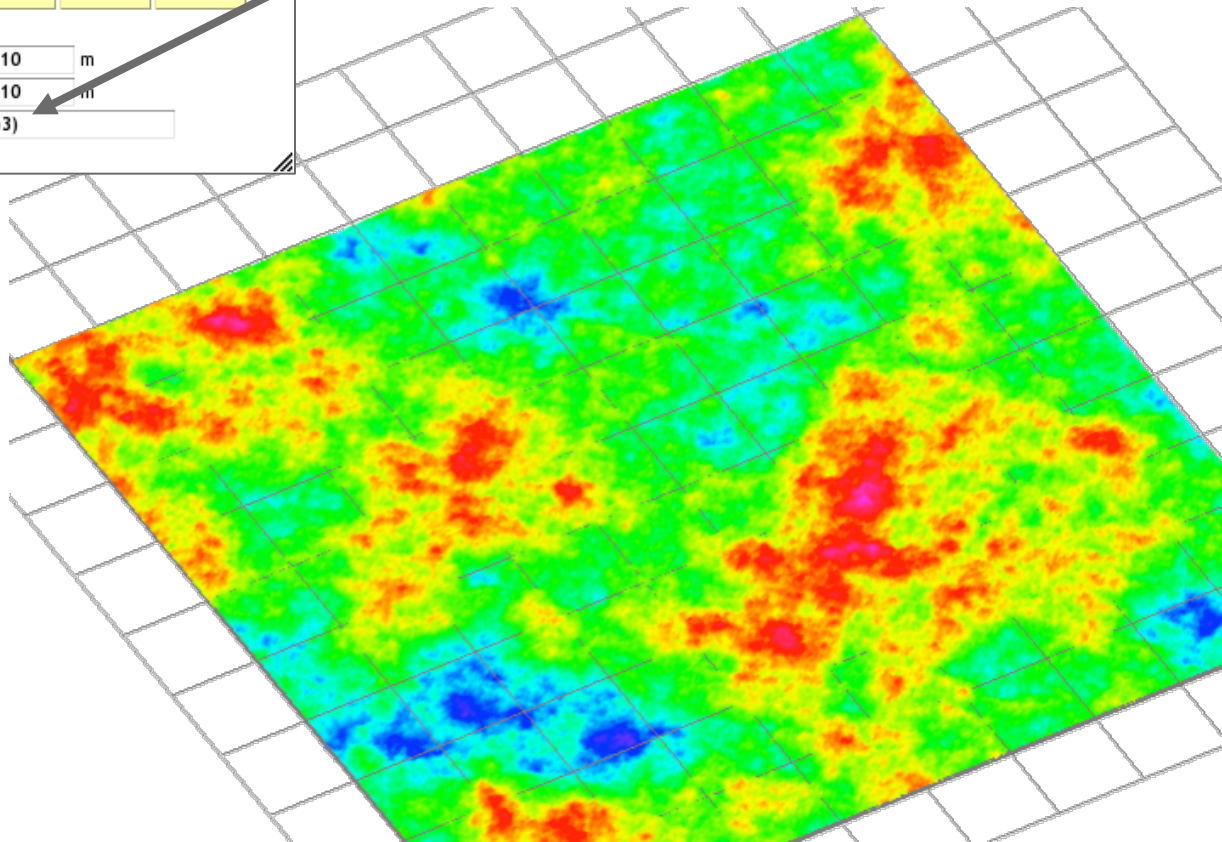


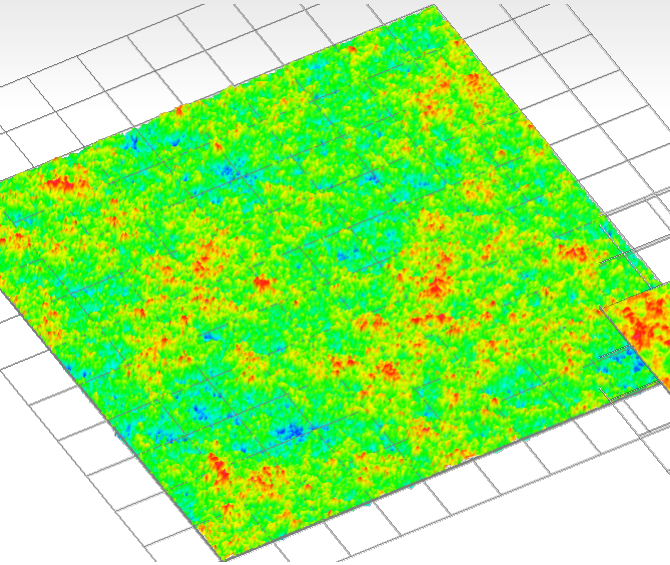


2D spectral density

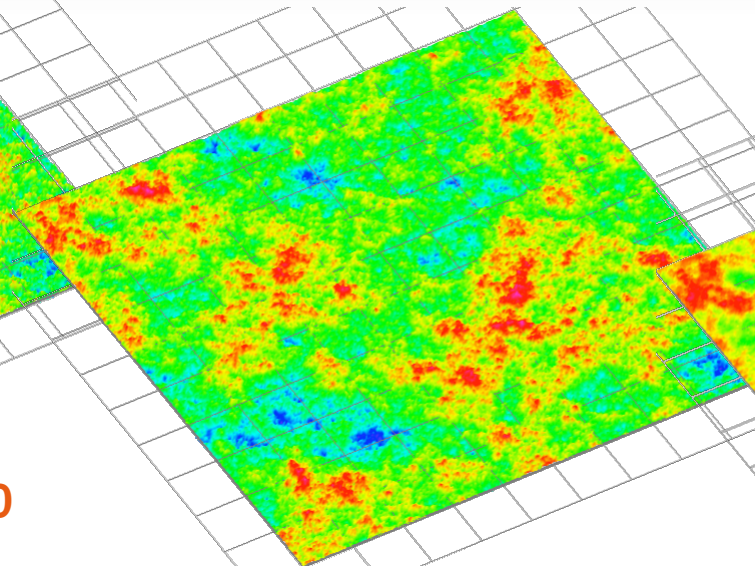
$$S(\Omega_x,\Omega_y)=\frac{10p_1}{\max\left(0.01,\Omega_x^{p_3}+\left(p_2\cdot\Omega_y\right)^{p_3}\right)}$$



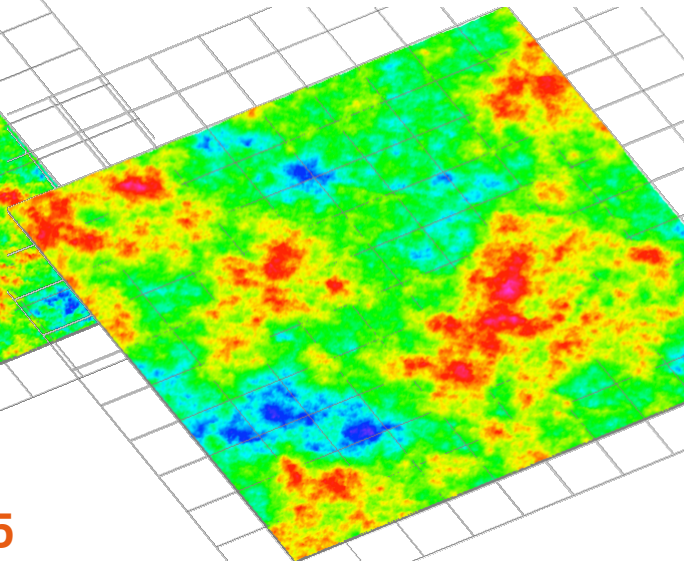




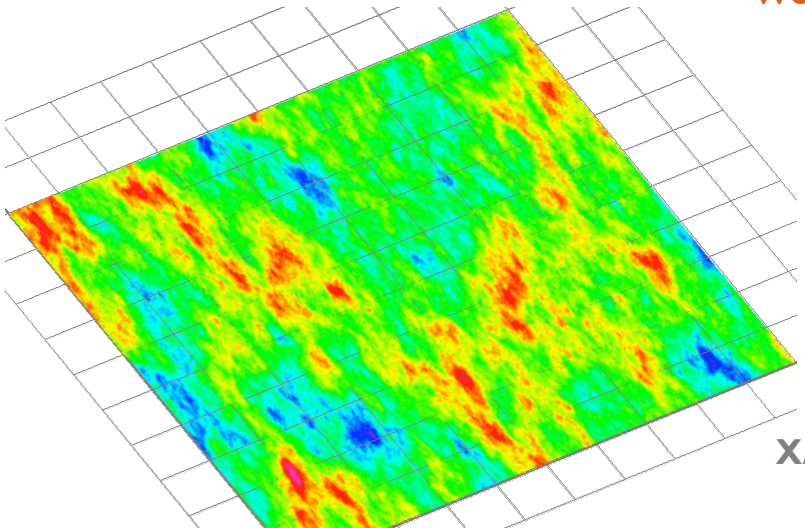
waviness p_3= 2.0



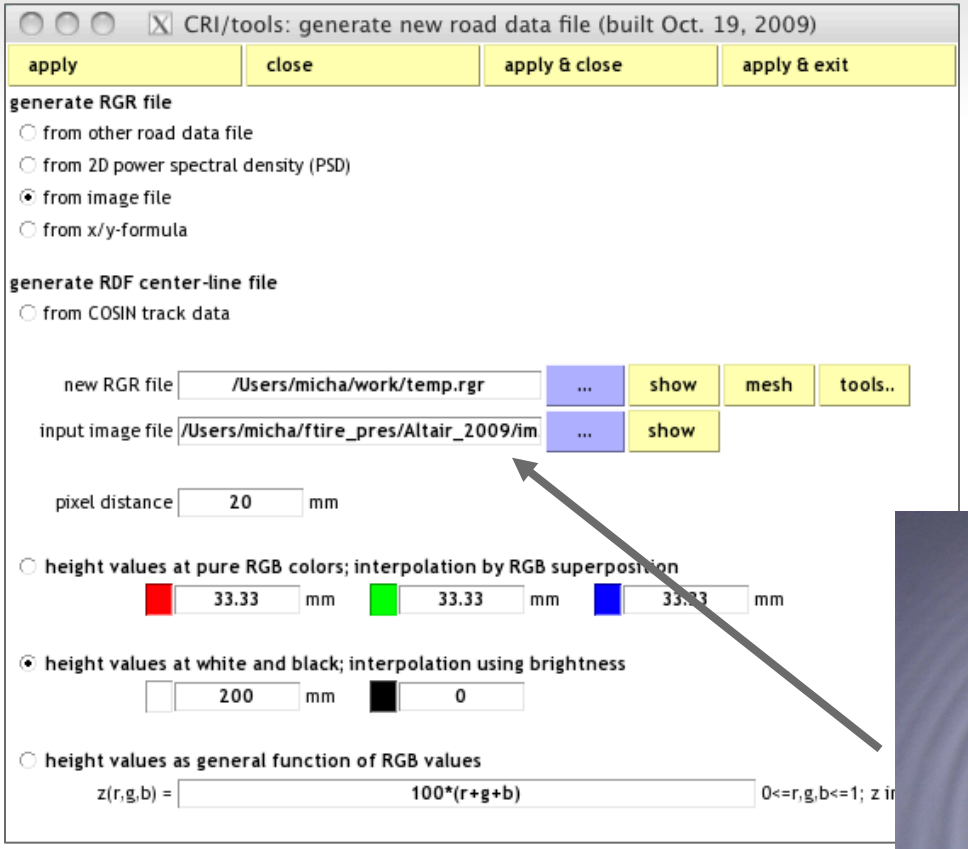
waviness p_3= 2.5



waviness p_3= 3.0

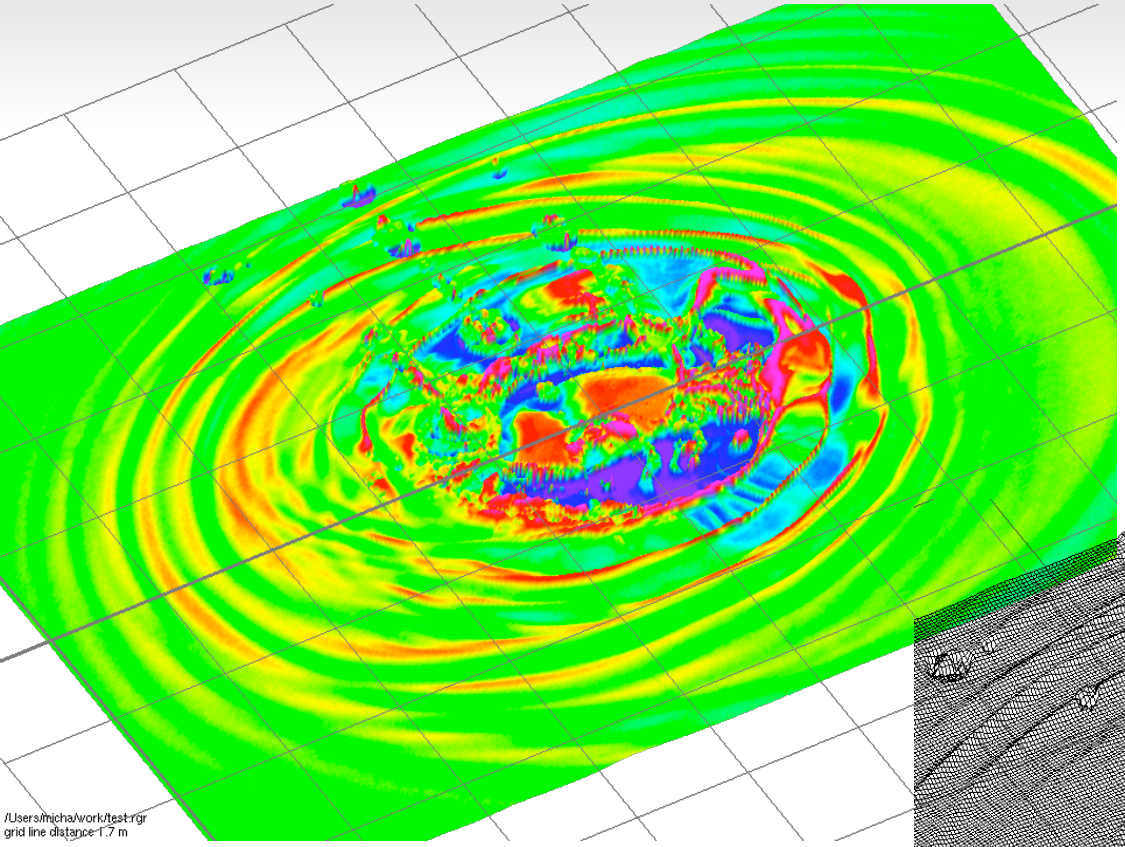


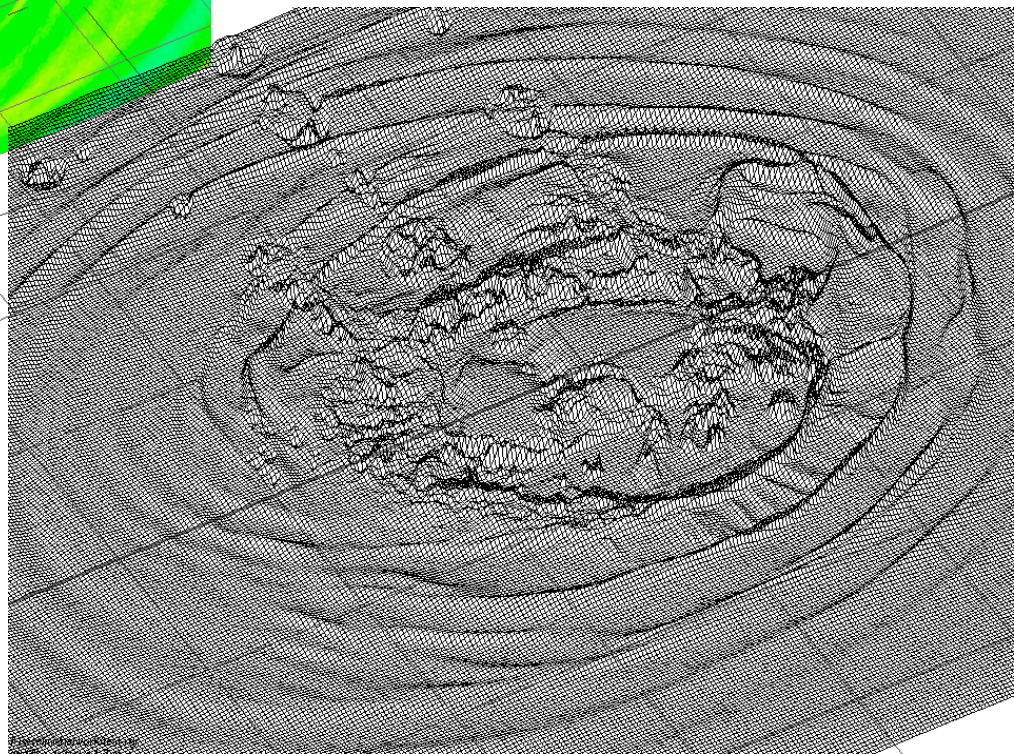
x/y anisotropy factor p_2= 3.0



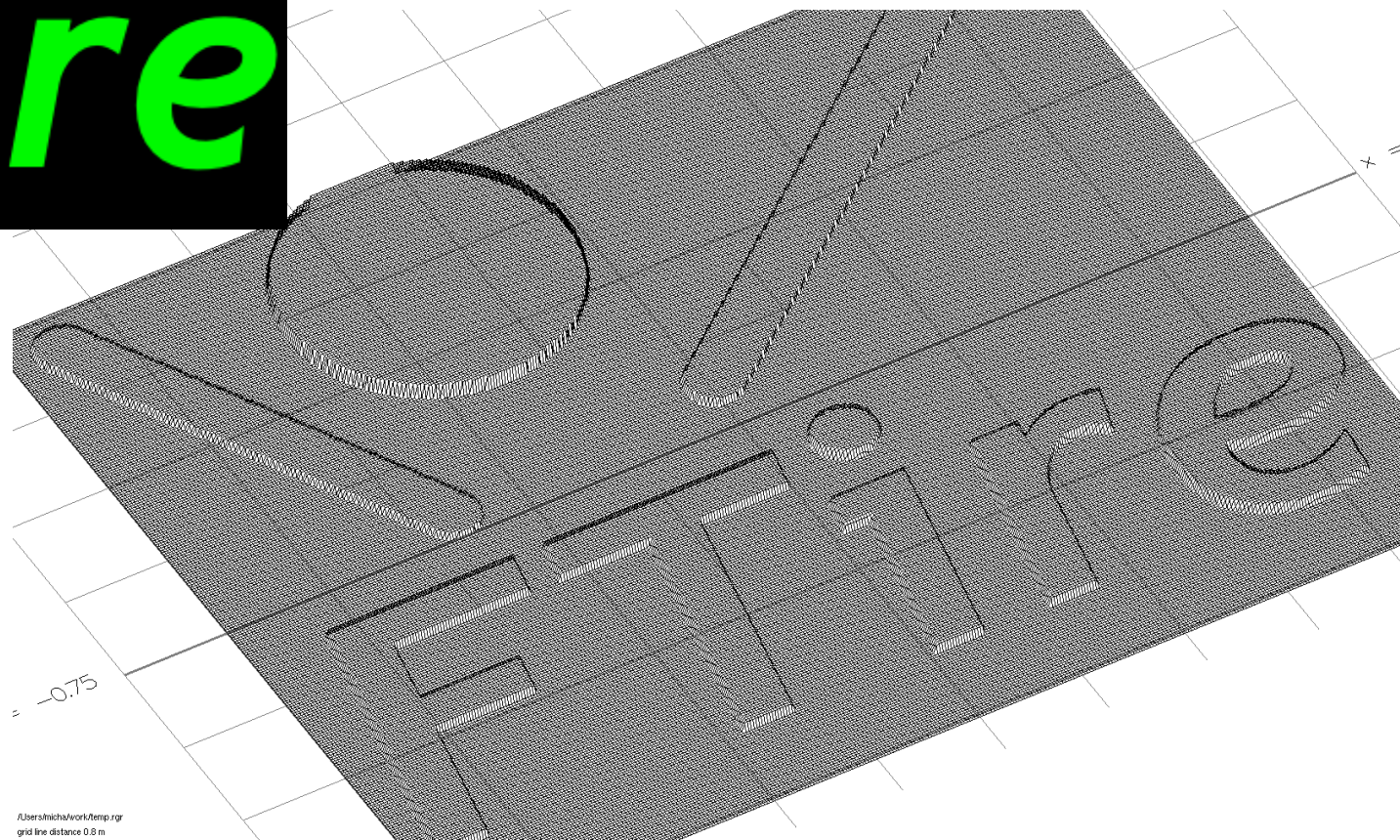
digital image

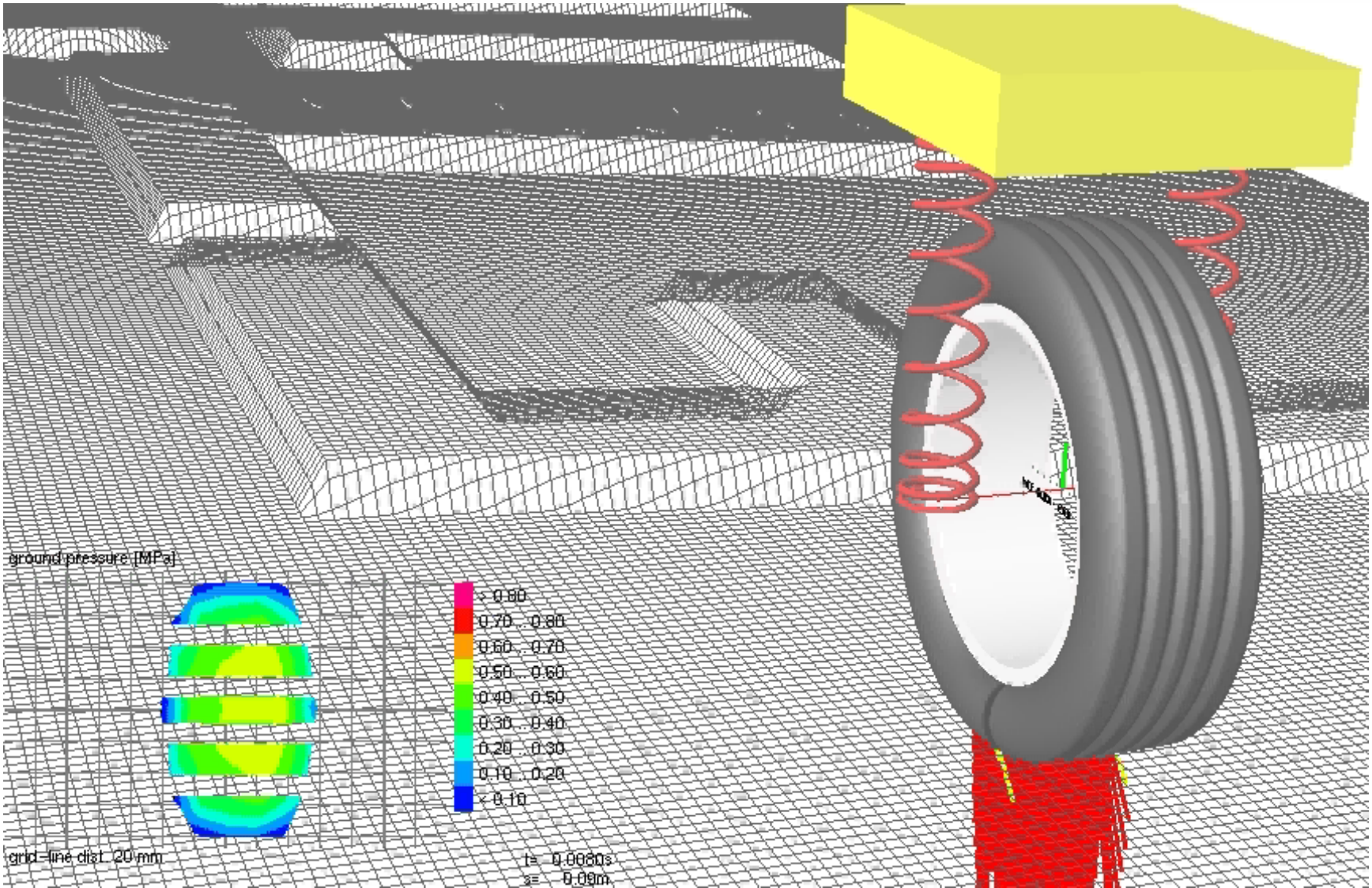
FTire
CRI/tools: RGR File Generation (6)





easy generation of single obstacles
by using a paint program




ground pressure [MPa]
> 0.80
0.70 .. 0.80
0.60 .. 0.70
0.50 .. 0.60
0.40 .. 0.50
0.30 .. 0.40
0.20 .. 0.30
0.10 .. 0.20
< 0.10
grid-line dist. 20 mm
t= 0.0080s
s= 0.09m

FTire interpolates tire's spatial contact forces onto a common regular grid

after every integration step, ***FTire*** calls **soil** model, passing over common grid position and nodal forces

soil model takes forces to update its states and soil surface geometry

soil model interpolates surface data onto the common grid, and passes it back to ***FTire***

USM = User-Defined Soft Soil Model Plug-In

detailed interface description in SAE 2008-01-1410

```
void soil_model_interface (

 double x0, double dx, int nx, double y0, double dy, int ny, double phi,
 double Fx[ ], double Fy[ ], double Fz[ ],
 double z[ ], double vx[ ], double vy[ ], double vz[ ], double mu[ ],
 int tire_handle, int calling_mode, double dt, char* soil_model_data_file) {

  /*  calling_mode = 0:
         initialize soil model instance
      calling_mode = 1:
         call the soil model which applies the contact forces and updates its
         state variables according to time-step dt; compute and return new
         grid elevations and velocities for soil-model instance
      calling_mode = 99:
         terminate model instance                                          */
  ...
}
```

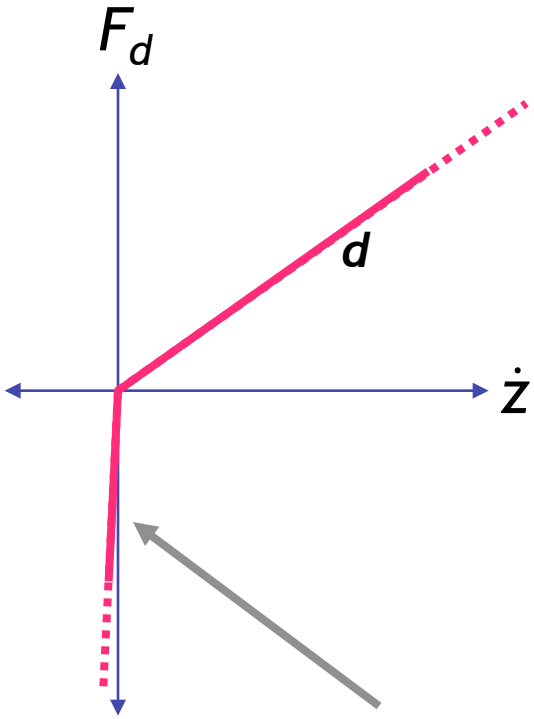
$$F_d(\dot{z}) + k \cdot (z - z_0) + p_{cont} = 0$$

$$k = 0.2 \frac{MPa}{mm} \qquad d = 10^{-5} \cdot k$$

$z_o(x,y)$ undeformed surface height

$z(x,y)$ deformed surface height

$p_{cont}(x,y)$ local contact pressure



persistent soil compaction

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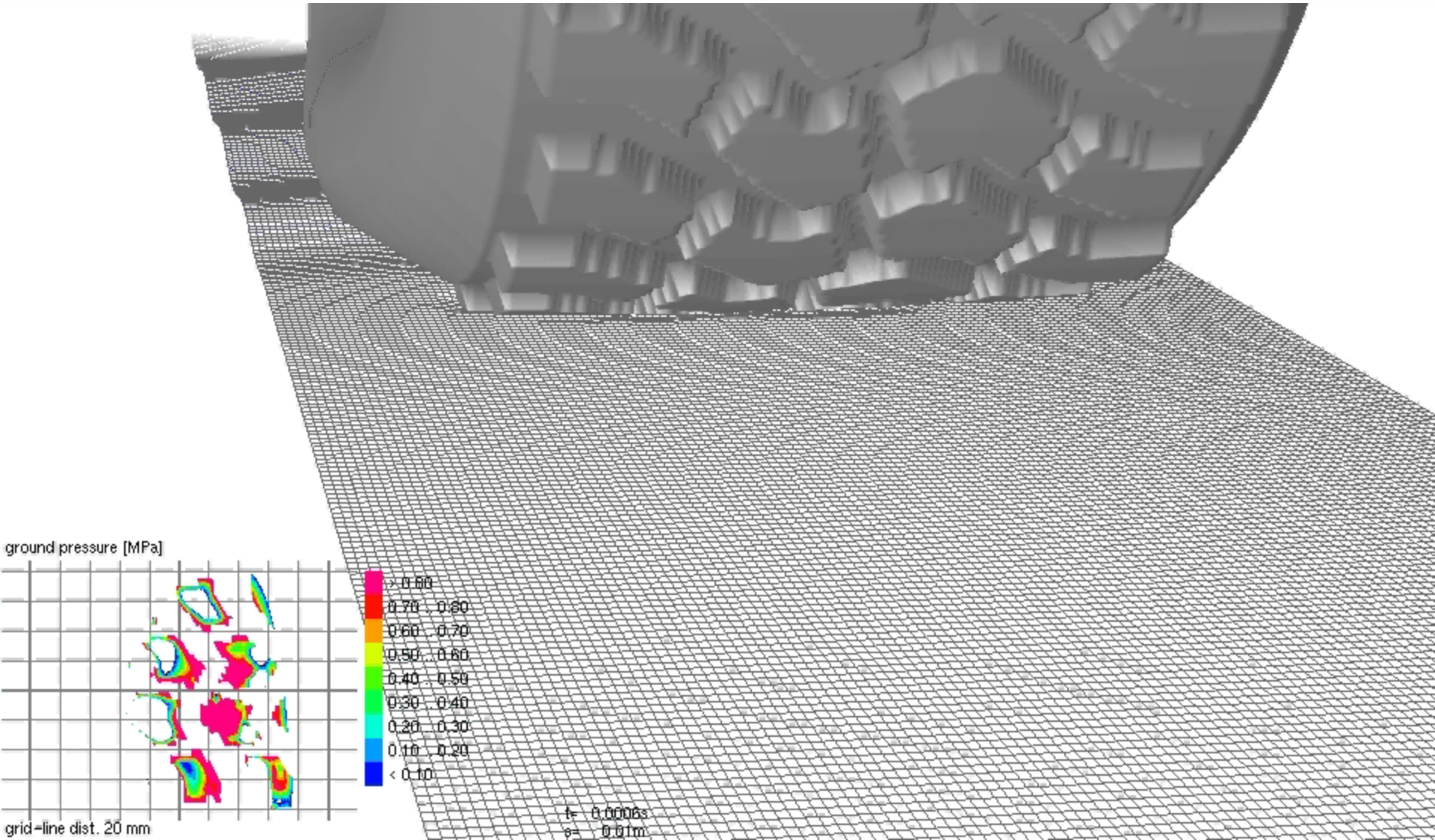
scientific software

FTire
Simulation with Internal Soil Model



..thank you for your attention!

Q & A

FTire etc.
demo versions,
papers,
animations,
documentation,
version updates,
and more:

www.cosin.eu