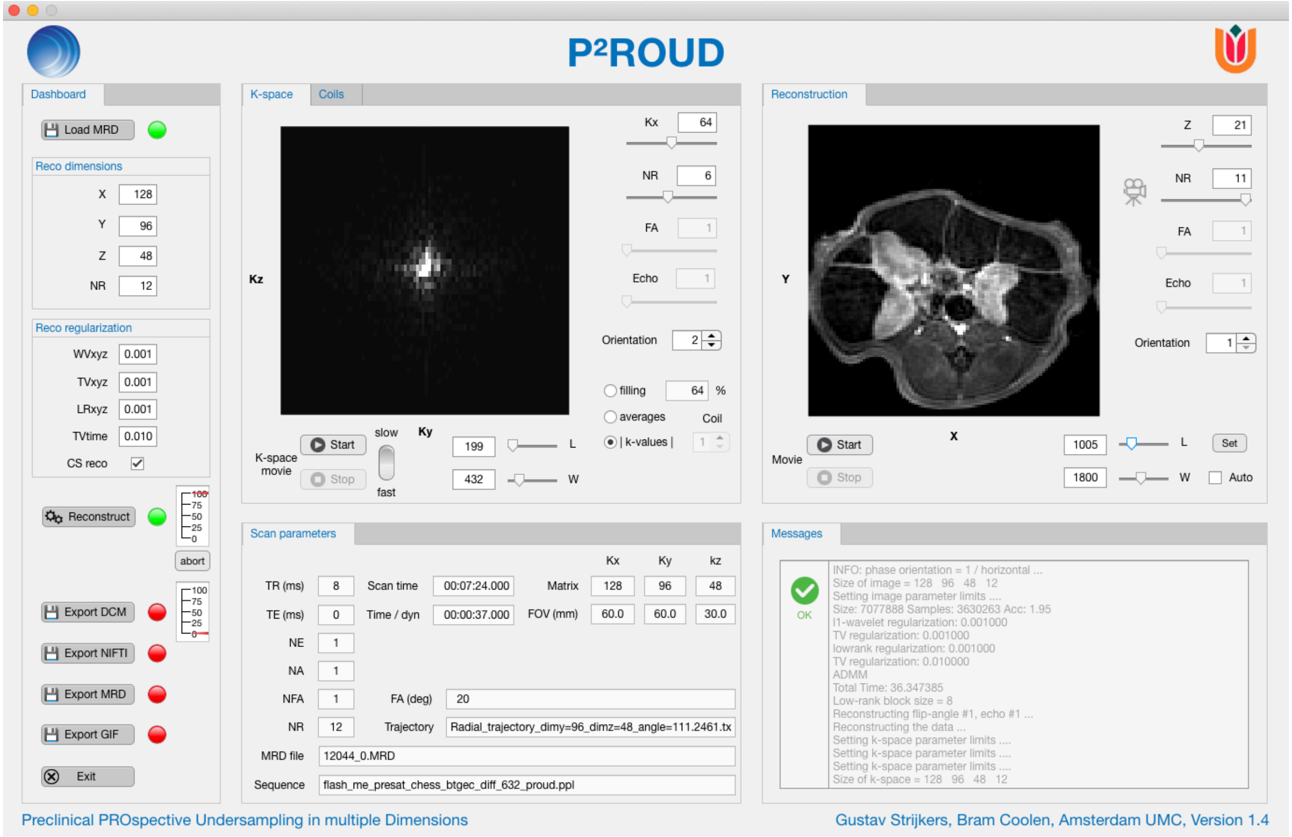

Reco dimensions

X	128
Y	96
Z	48
NR	12

Reco regularization

WVxyz	0.001
TVxyz	0.001
LRxyz	0.001
TVtime	0.010
CS reco	☑

K-space: Kx 64; NR 6; FA 1; Echo 1; Orientation 2; ○ filling 64 %; ○ averages; ● | k-values |; Coil 1; L 199; W 432

Reconstruction: Z 21; NR 11; FA 1; Echo 1; Orientation 1; L 1005; W 1800; ☐ Auto

Scan parameters

					Kx	Ky	kz
TR (ms)	8	Scan time	00:07:24.000	Matrix	128	96	48
TE (ms)	0	Time / dyn	00:00:37.000	FOV (mm)	60.0	60.0	30.0
NE	1						
NA	1						
NFA	1	FA (deg)	20				
NR	12	Trajectory	Radial_trajectory_dimy=96_dimz=48_angle=111.2461.tx				

MRD file: 12044_0.MRD

Sequence: flash_me_presat_chess_btgec_diff_632_proud.ppl

```
INFO: phase orientation = 1 / horizontal ...
Size of image = 128   96   48   12
Setting image parameter limits ....
Size: 7077888 Samples: 3630263 Acc: 1.95
l1-wavelet regularization: 0.001000
TV regularization: 0.001000
lowrank regularization: 0.001000
TV regularization: 0.010000
ADMM
Total Time: 36.347385
Low-rank block size = 8
Reconstructing flip-angle #1, echo #1 ...
Reconstructing the data ...
Setting k-space parameter limits ....
Setting k-space parameter limits ....
Setting k-space parameter limits ....
Size of k-space = 128   96   48   12
```

Preclinical PROspective Undersampling in multiple Dimensions

Gustav Strijkers, Bram Coolen, Amsterdam UMC, Version 1.4

Table of contents

1. Overview

P2ROUD = Preclinical PROspective Undersampling in multiple Dimensions

P2ROUD is a software utility and graphical user interface to reconstruct MRI acquisition from data with k-space undersampling in one or more dimensions acquired with an MR Solutions preclinical MRI system.

2. Contact

P2ROUD and this manual are written by:

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3. Disclaimer

The software has been extensively tested using mouse and rat data acquired with an MR Solutions preclinical 7.0T/24cm system.

However, this does not warrant the functions contained in the program will meet your requirements or that the operation of the program will be uninterrupted or error-free.

In case of questions or issues, please contact Gustav Strijkers or Bram Coolen.

4. Installation notes

Software download

Matlab source code and a Windows standalone version (using the free Matlab runtime engine) can be downloaded from github:

`https://github.com/Moby1971?tab=repositories`

Installation of the Windows standalone version

`MyAppInstaller_web.exe`

Will install the Matlab runtime engine and the P2ROUD program.

Bart toolbox download

The advanced reconstruction options in P2ROUD require the Bart reconstruction toolbox, which can be downloaded from:

`https://mrirecon.github.io/bart/`

Bart toolbox installation in OSX with MacPorts

(1) Install Xcode from the Mac App Store

```
$ xcode-select --install
```

(2) Install MacPorts (`http://www.macports.org/`)
It is recommended to install a newer version of gcc from MacPorts

(3) Install packages

```
$ sudo port install fftw-3-single
$ sudo port install gcc11
$ sudo port install libpng
$ sudo port install openblas
```

(4) Make

```
- replace 'gcc-mp-6' with 'gcc-mp-11' in Makefile
$ make
```

Bart toolbox installation in OSX with HomeBrew (for Mac with Apple Silicon)

(1) Install Xcode from the Mac App Store

```
$ xcode-select --install
```

(2) Install HomeBrew

```
$ /bin/bash -c "$(curl -fsSL https://raw.githubusercontent.com/
Homebrew/install/HEAD/install.sh)"
```

(3) Install packages

```
$ brew install --cask gcc-arm-embedded
$ brew install libpng
$ brew install fftw
$ brew install openblas
```

(3) Make

```
- Use the provided makefile for Apple Silicon
$ make
```

Bart toolbox installation in Windows 10

(1) Install the Windows subsystem for Linux

Start a windows powershell and run the following command:

```
Enable-WindowsOptionalFeature -Online -FeatureName Microsoft-Windows-Subsystem-Linux
```

A system restart will be needed.

For more information, see:

`https://docs.microsoft.com/en-us/windows/wsl/install-win10`

(2) Download Ubuntu Linux 18.04

For more information see:

`https://docs.microsoft.com/en-us/windows/wsl/install-manual`

Install the `appx` file by double-clicking in Explorer or in a PowerShell command prompt:

```
Add-AppxPackage .\app_name.appx
```

You will be asked to create a user account the first time you start a Linux command prompt.

(3) Upgrade the Linux distribution

```
$ sudo apt-get update
$ sudo apt-get dist-upgrade
```

(4) Install Bart prerequisites

```
$ sudo apt-get install make gcc libfftw3-dev liblapacke-dev
  libpng-dev libopenblas-dev gfortran
```

(5) Download Bart

```
$ wget https://github.com/mrirecon/bart/archive/v0.7.00.tar.gz
```

For WSL1 version 0.4.02 is recommended. Newer versions seem to compile but some functions which are required produce errors. Upgrade to WSL2 for higher versions (see e.g. https://pureinfotech.com/install-windows-subsystem-linux-2-windows-10/ on how to upgrade).

(6) Build Bart

```
$ tar xvfz v0.7.00.tar.gz
$ cd bart-0.7.00
$ make
$ sudo make PREFIX=/usr/local install
```

5. Running the software

Running in Matlab 2021a

The P2ROUD software can be started from its root directory from the command line.

```
>> P2ROUD
```

Notes:

(1) The P2ROUD root directory `~/P2ROUDX.X-master` contains the following 3 text files:

`bartpath.txt` Bart toolbox installation directory
Delete this file if the Bart toolbox is not available on your system

`mrdpath.txt` Shortcut to base directory in which the MRI scanner-generated MRD files can be found

Make sure that the text files contain exactly 1 line of text

(2) Additional licenses may be required.

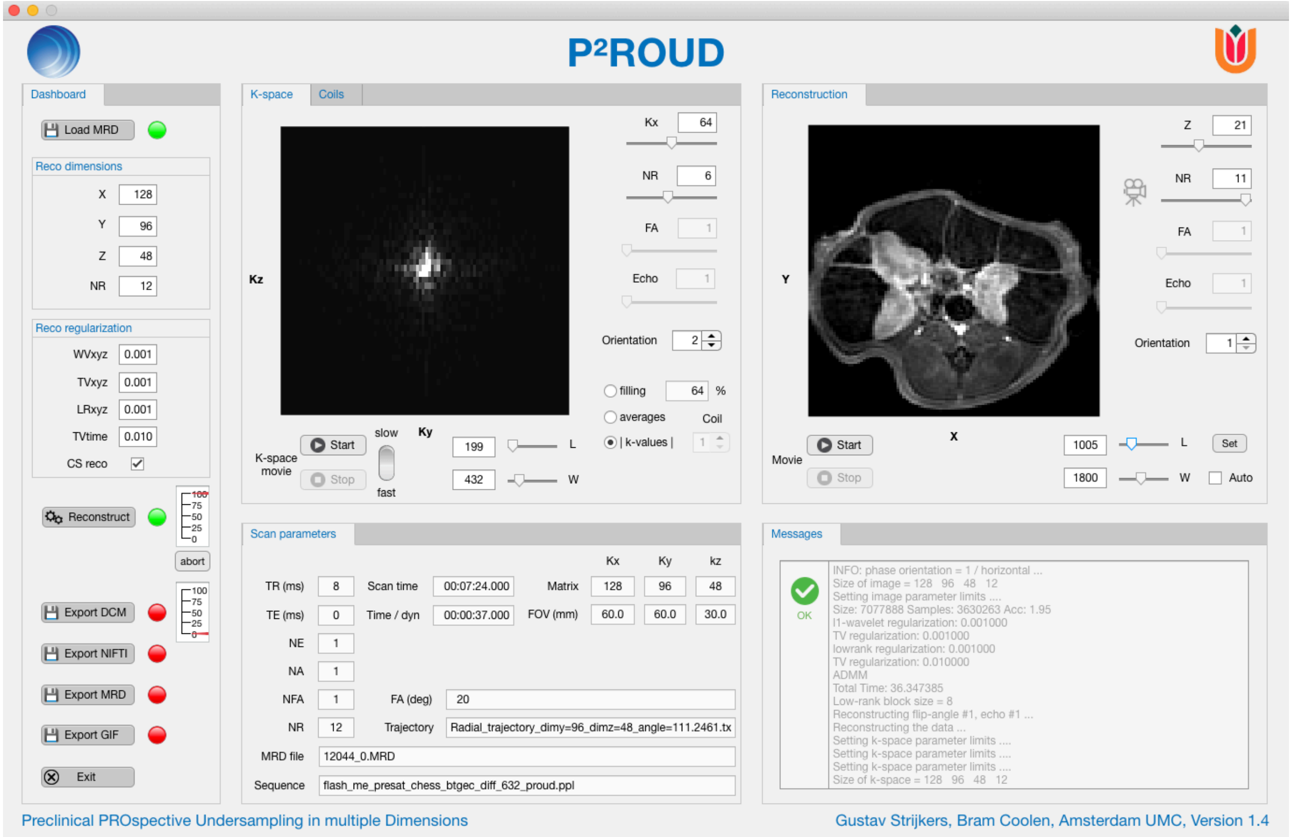
```
>> license 'inuse'
image_toolbox
matlab
signal_toolbox
statistics_toolbox
```

Running the Windows standalone

The Windows standalone version can be run from the start menu or the desktop icon.

6. Basic operation

The P2ROUD program operates from a single window with 5 panels.



Reco dimensions

X 128
Y 96
Z 48
NR 12

Reco regularization

WVxyz 0.001
TVxyz 0.001
LRxyz 0.001
TVtime 0.010
CS reco ☑

K-space: Kx 64, NR 6, FA 1, Echo 1, Orientation 2, ○ filling 64 %, ○ averages, ● | k-values |, Coil 1, L 199, W 432

Reconstruction: Z 21, NR 11, FA 1, Echo 1, Orientation 1, L 1005, W 1800, □ Auto

Scan parameters

					Kx	Ky	kz
TR (ms)	8	Scan time	00:07:24.000	Matrix	128	96	48
TE (ms)	0	Time / dyn	00:00:37.000	FOV (mm)	60.0	60.0	30.0
NE	1						
NA	1						
NFA	1	FA (deg)	20				
NR	12	Trajectory	Radial_trajectory_dimy=96_dimz=48_angle=111.2461.tx				

MRD file 12044_0.MRD

Sequence flash_me_presat_chess_btgec_diff_632_proud.ppl

Messages

```
INFO: phase orientation = 1 / horizontal ...
Size of image = 128   96   48   12
Setting image parameter limits ....
Size: 7077888 Samples: 3630263 Acc: 1.95
l1-wavelet regularization: 0.001000
TV regularization: 0.001000
lowrank regularization: 0.001000
TV regularization: 0.010000
ADMM
Total Time: 36.347385
Low-rank block size = 8
Reconstructing flip-angle #1, echo #1 ...
Reconstructing the data ...
Setting k-space parameter limits ....
Setting k-space parameter limits ....
Setting k-space parameter limits ....
Size of k-space = 128   96   48   12
```

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Panel 1: Dashboard

This panel contains the task buttons and parameters that control the reconstruction process. The dashboard tasks need to be completed from top to bottom. A green light next to the task indicates that the task has been completed. When the light is yellow the task is busy. Red indicates not completed yet.

Panel 2: K-space / Coils

This panel shows the raw k-space data.

Panel 3: Scan parameters

This panel displays the relevant acquisition parameters.

Panel 4: Reconstruction

After reconstruction is completed this panel shows the reconstructed images.

Panel 5: Messages

Displays program status and messages.

Step 1: Loading data

Press Load MRD to import load the MRD raw data file.

P2ROUD in principle can reconstruct any spin-echo, fast-spin echo, and gradient-echo data (except epi).

However the program is particularly designed to reconstruct undersampled data with user-defined undersampling pattern (e.g. SENSE, random undersampling, pseudo-spiral or radial).

For data acquired with multiple receivers (phased-array RF coil) select 1 of the MRD files.

Relevant acquisition parameters will be shown in panel 3.

k-space trajectory

Currently there are 2 options to include a user-defined k-space trajectory in the FLASH (version 634) sequence.

(1) **2D-data**

pe1-order = 3

The k-space points for the 1st phase-encoding direction (views) are provided in the views-table in the sequence.

(2) **3D-data**

pe1-order = 4

The k-space points for the 1st and 2nd phase-encoding directions (views and views2) are provided in a text file (*.txt) as a list of points without comma separation.

For example:

```
-48       (views    k-point 1)
0         (views2   k-point 1)
-47       (views    k-point 2)
0         (views2   k-point 2)
-46       .
1         .
-45       .
.
.
etc...
```

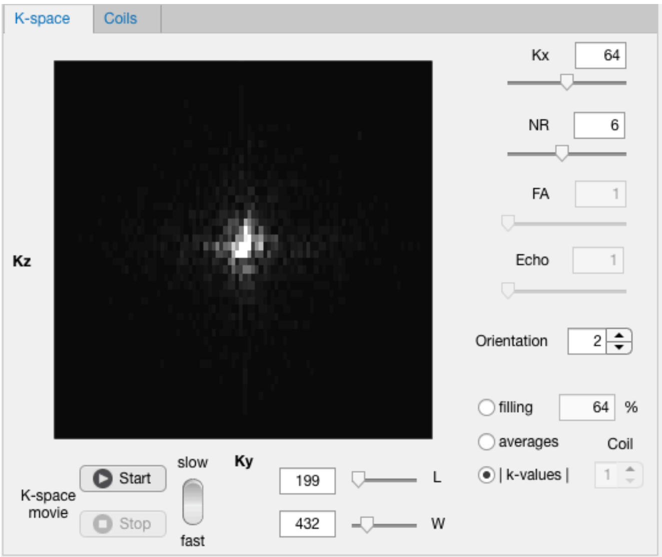
The list has to be up-loaded to the EVO using c:\smis\UploadData.exe just before the acquisition is started.

NOTE ! The list file has to be manually placed in the corresponding MRD directory when loading the data in P2ROUD.

A Matlab file (**radialtrajectory.m**) for making a pseudo-radial trajectory can be found in the directory /Trajectories.

Step 2: Inspecting k-space

The raw k-space data is displayed in panel 2.



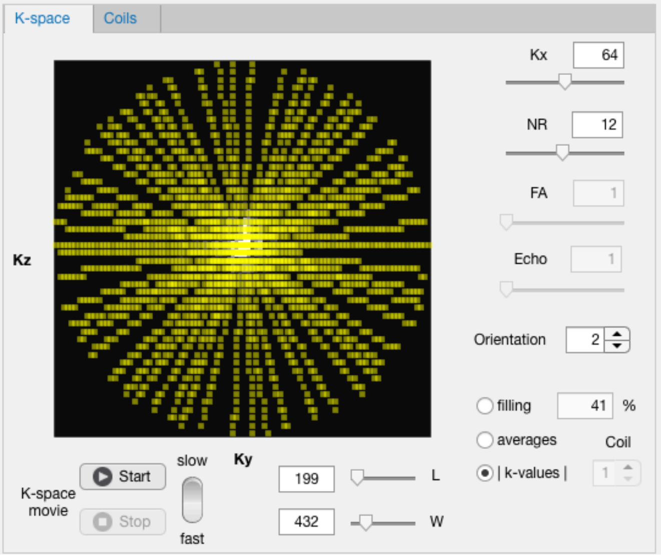
Kx 64
NR 6
FA 1
Echo 1
Orientation 2
○ filling 64 %
○ averages
● | k-values |
199 L
432 W

The window displays either the acquired k-space points (**filling**), the number of averages per k-point (**averages**), or the absolute value of k-space (**|k-values|**). The percentage of k-space points acquired is indicated (64% for this dataset).

The sliders step through the 3rd k-space dimension, slices, repetitions (**NR**), flip angles (**FA**) and echoes (**Echo**), if applicable. You can toggle the orientation with the toggle buttons.

Step 3: Displaying the k-space trajectory

Press Start to start an animation of the k-space trajectory. An example for a pseudo-radial k-space trajectory is shown below

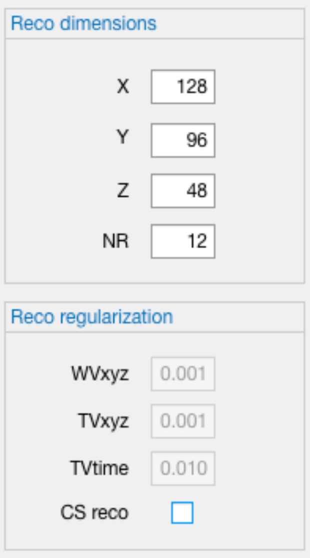


Kx 64
NR 12
FA 1
Echo 1
Orientation 2
○ filling 41 %
○ averages
● | k-values |
199 L
432 W

Press Stop to stop the animation. Press fast slow to toggle between fast and slow animation speed.

Step 4: Fourier transform reconstruction

For a first quick inspection of the reconstructed images, a Fourier transform reconstruction of the data can be done by un-checking the **CS reco** box and pressing Reconstruct .



Reco dimensions

X 128

Y 96

Z 48

NR 12

Reco regularization

WVxyz 0.001

TVxyz 0.001

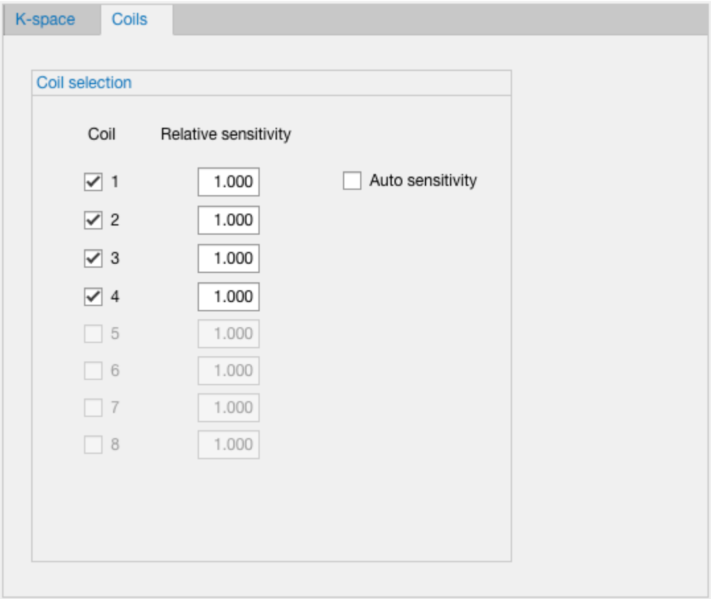
TVtime 0.010

CS reco □

The spatial dimensions of the reconstructed data can be increased or decreased, which will result in zero-padding or cropping of k-space. The number of repetitions (**NR**) cannot be changed when performing a Fourier transform reconstruction.

Step 5: Coils panel

For acquisitions performed with a phased-array coil the **Coils** panel gives access to the different channels. Here coils can be checked/unchecked to be considered/omitted in the reconstruction. Relative coil sensitivities can be changed or automatically determined by checking the Auto sensitivity checkbox.



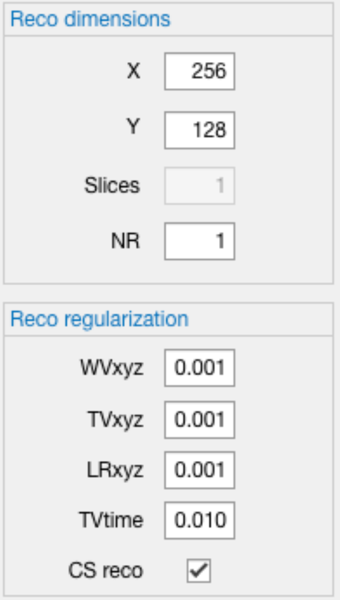
Coil selection

Coil	Relative sensitivity
☑ 1	1.000
☑ 2	1.000
☑ 3	1.000
☑ 4	1.000
□ 5	1.000
□ 6	1.000
□ 7	1.000
□ 8	1.000

□ Auto sensitivity

Step 6: Compressed sensing reconstruction

Checking the **CS reco** box gives access to the Compressed Sensing (CS) reconstruction parameters.



Reco dimensions

X 256

Y 128

Slices 1

NR 1

Reco regularization

WVxyz 0.001

TVxyz 0.001

LRxyz 0.001

TVtime 0.010

CS reco ☑

The CS regularization parameters are:

(1) **WVxyz**

Wavelet regularization parameter in the spatial (x, y, and z) dimensions.

(2) **TVxyz**

Total variation constraint in the spatial dimensions.

(3) **LRxyz**

Locally Low Rank constraint in the spatial dimensions.

(4) **TVtime**

Total variation constraint in the dynamics (repetitions / **NR**) dimension.

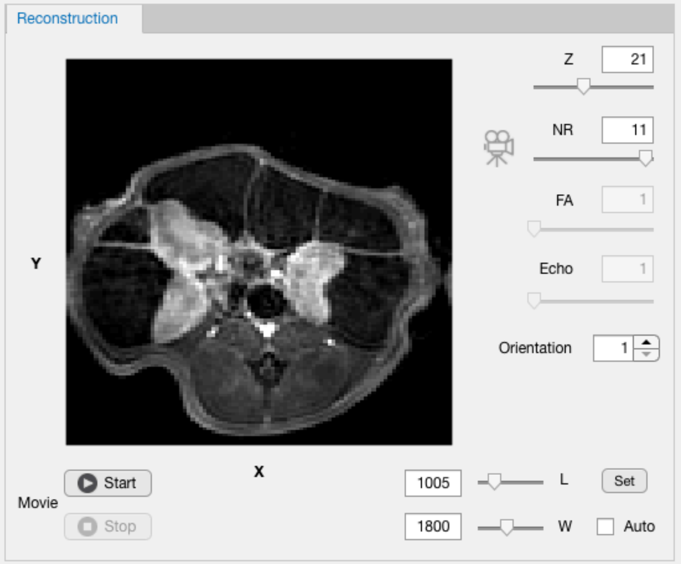
The spatial dimensions of the reconstructed data can be increased or decreased. The number of repetitions (**NR**) can also be changed to undersample or average data in the dynamics dimension.

Pressing [Reconstruct] will start the CS reconstruction with the BART toolbox.

If the BART toolbox is not available CS reconstruction will be done using a CS algorithm implemented in Matlab, which can be very slow for large datasets.

Step 7: Viewing the reconstructed images

After reconstruction the MR images are displayed in panel 4.



Z 21

NR 11

FA 1

Echo 1

Orientation 1

L 1005

W 1800

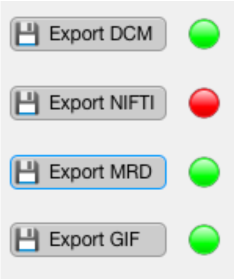
□ Auto

The image orientation can be changed by pressing the **Orientation** toggle buttons.

Image intensity can be adjusted with the **Level** and **Window** sliders. Checking **Auto level** will result in automatic intensity adjustment.

Press ▶ Start to start a movie of images as function of the dimension / parameter shown next to the camera icon 🎥 .

Step 8: Image export



There are several ways to export the images.

(1) **Export DCM**

Exports the data in Dicom format for further processing in 3rd party software. The program searches for the Dicom information. If this information is not found, tags will be generated by the program itself. In the latter case the correct image position and orientation information are lost.

(2) **Export NIFTI**

Exports 3D and 3D-time data in NIFTI format for further processing in 3rd party software.

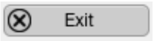
(3) **Export MRD**

The data will be stored as a new MRD data file in the same directory as the input MRD file. If the program finds an input rpr file, also a new rpr file will be generated. Additionally, when the program runs on the scanner computer, data will be reconstructed by the scanner software and new SUR files will be placed in the data directory for viewing and planning of next scans in the MR Solutions preclinical software.

(4) **Export GIF**

The data will be exported as (animated) gif files.

Step 9: Exit

Press  to shut down the program.