MRIsim.jl: Toolbox for spin-level simulations

Project presentation

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Motivation

“Being as far as possible from models”

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- Closer to reality
- Applicable to multiple problems
- Can help to test novel methods

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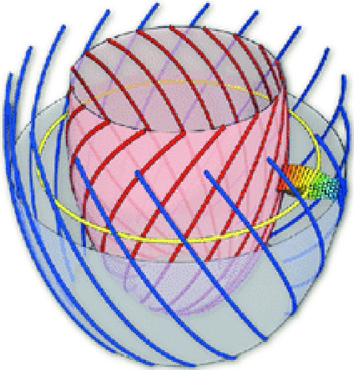
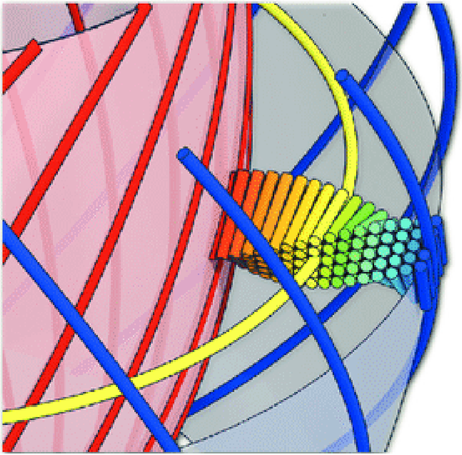
- Closer to reality
- Applicable to multiple problems
- Can help to test novel methods

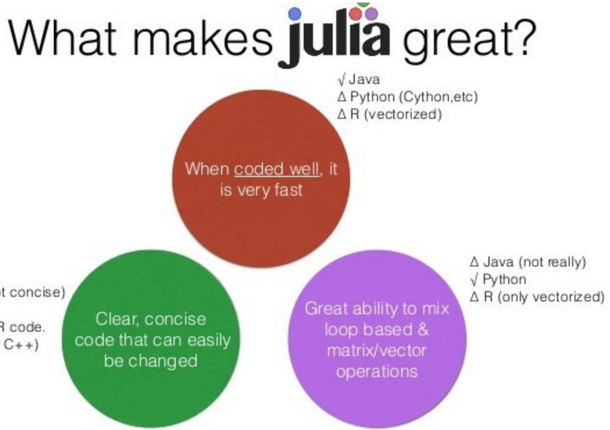
- Speed (GPU and parallelization)

Other simulators were not **general enough** to match our needs





For this we used Julia: **Fast** and **easy to write**

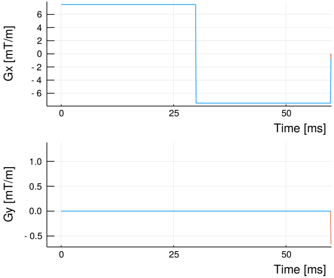


Examples in our simulator:
Gradient and Sequence objects

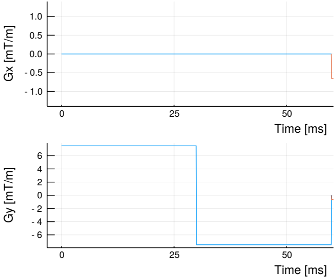
```julia
## Grad.jl
struct Grad
    A::Real #Amplitud [T]
    T::Real #Duration of gradient [s]
    DAC::Bool #If we take data during that period
end
## Sequence.jl
struct Sequence
    GR::Array{Grad,2}   #Sequence in (X, Y and Z) and Time
end
```

Scalar and matrix multiplication

```
## Grad.jl: Gradient operations
*(x::Grad, α::Real) = Grad(α*x.A,x.T,x.DAC)
*(x::Array{Grad}, A::Matrix) = [sum(x[i,:]*A[j,i] for i=1:size(x,
    1))[k] for j=1:size(x,1), k=1:size(x,2)] #matrix-mult
## Sequence.jl: Sequence operations
*(x::Sequence, A::Matrix) = Sequence(x.GR*A)
```

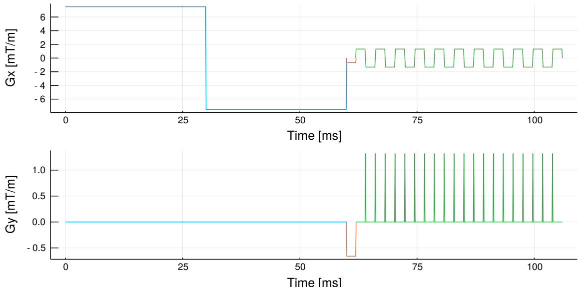


$$\cdot \mathrm{R}_z\left(\theta\right) =$$



Pulse programming example

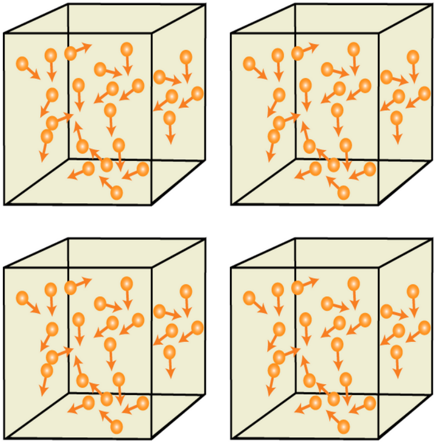
```
## Sequence.jl: Sequence operations
+(x::Sequence, y::Sequence) = Sequence([x.GR y.GR])
## Example.jl
DIFF = Sequence([Grad(G,T) Grad(-G,T); #PGSE on x-dir
                 Grad(0,T) Grad( 0,T)])
SEQ = q*DIFF*rotz(θ) + PHASE + EPI
```



Simulator

After excitation the signal depends on the spin phases

$$\phi_n(\boldsymbol{x}, t) = \gamma \int_0^t \Big(\underbrace{\boldsymbol{x}_n(\tau) \cdot \boldsymbol{G}(\tau)}_{\substack{k\text{−space enconding}\\ \text{including motion.}}} + \underbrace{\delta B\left(\boldsymbol{x}_n^0\right)}_{\text{off-resonance}} \Big)\, \mathrm{d}\tau.$$



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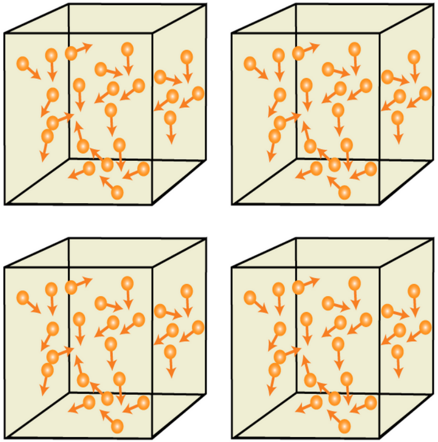
$$\boldsymbol{x}_n\left(t^{k+1}\right) = \underbrace{\boldsymbol{x}_n^0}_{\textbf{Position}} + \underbrace{\boldsymbol{\eta}\left(\boldsymbol{x}_n^0, t^k\right)}_{\textbf{Diffusion}} + \underbrace{\boldsymbol{u}\left(\boldsymbol{x}_n^0, t^k\right)}_{\textbf{Displacement}}$$



The signal equation considers all relevant effects

$$S\left(t^k\right) = \sum_{n=1}^{N_s} \boldsymbol{m}\left(\boldsymbol{x}_n^0\right) \exp\left(-t^k / T_2\left(\boldsymbol{x}_n^0\right) + i\Delta\omega\left(\boldsymbol{x}_n^0\right) t^k\right) \exp\left(i\gamma\Delta t \sum_{l=0}^{k} \boldsymbol{x}_n\left(t^l\right) \cdot \boldsymbol{G}\left(t^l\right)\right)$$

1. **Proton density,**
2. T2-decay,
3. Position, motion, flow and Diffusion,
4. Off-resonance (T2*, concomitant gradients, etc.).

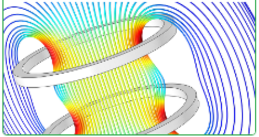
The simulator pipeline has **three** main objects

SpinLab — Scanner | Pulses | Phantom | Simulator | Recon.

Scanner

Description of the hardware limitations, such as B_0, B_1, $G_{\max}$, and $S_{\max}$.

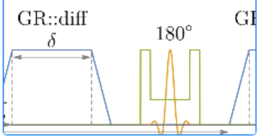
It is also possible to include field imperfections as an additional term $\Delta\boldsymbol{B}(\boldsymbol{x},\boldsymbol{G})$.



Pulses

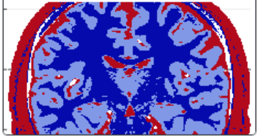
Sequence of pulses, including the gradients $\boldsymbol{G}(t)$ and RF $B_{1,e}(t)$ signals.

It can also visualize the k-space of the acquisistion.



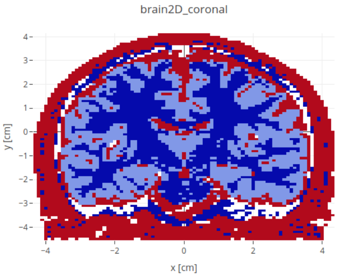
Phantom

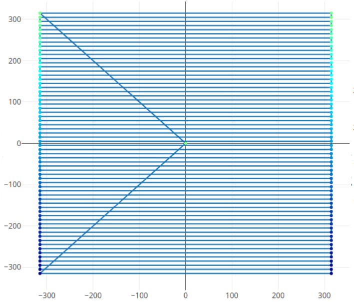
Definition of the phantom model, includes information about the proton density ρ, $\mathrm{T1}$, $\mathrm{T2}$, off-resonance $\Delta\omega$, diffusion, and displacement field $\boldsymbol{u}(\boldsymbol{x},t)$.

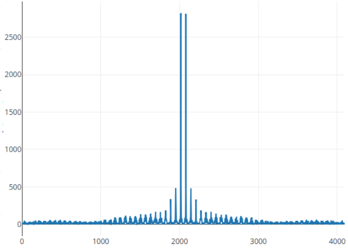


Run simulation!

Phantom→Scanner+Sequence→Signal







Examples

E1) Brain phantom with different TEs

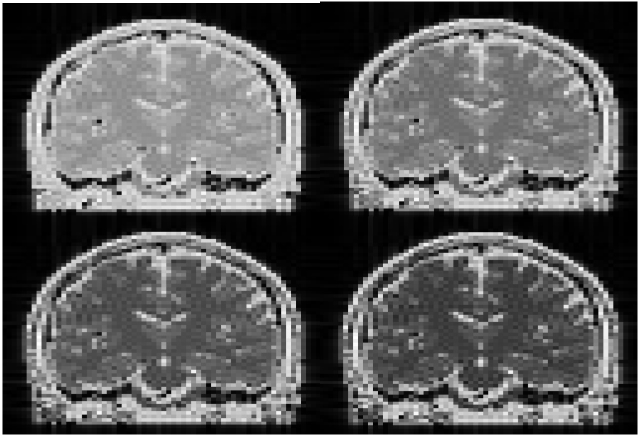
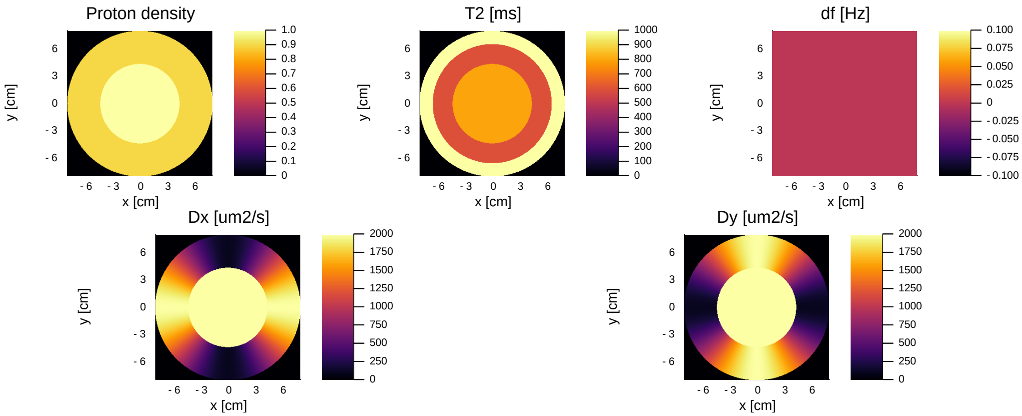


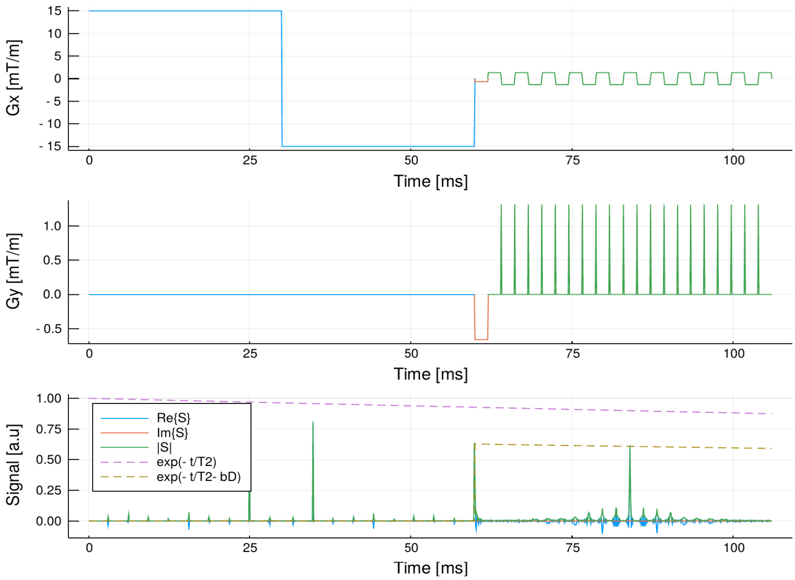
Figure 1: EPI acquisition with TE = $\{16, 30, 60, 80\}$ ms.

E2) Cardiac diffusion on static phantom

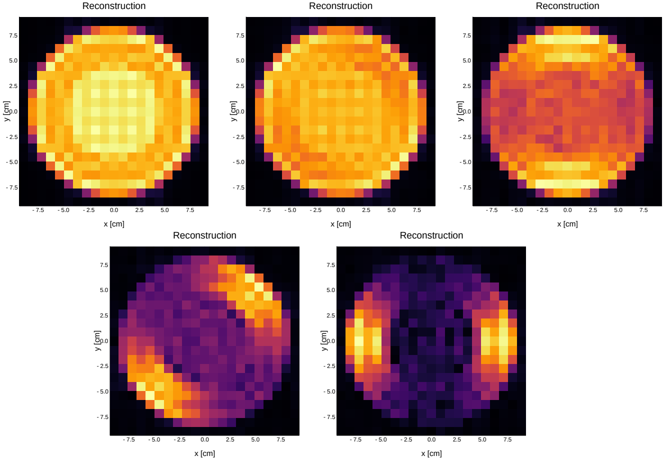
The phantom was defined by the following fields:

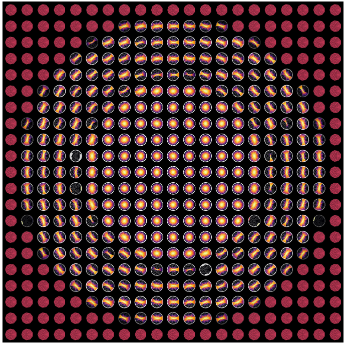


The sequence used was a PGSE



We acquired images with different diffusion encodings (left) and reconstructed the diffusion propagators (right)

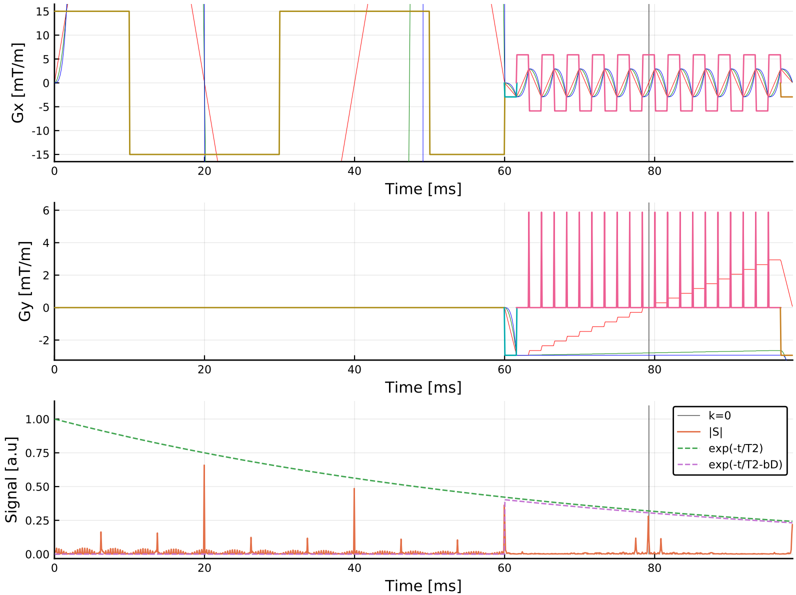




E3) Moment-compensated cardiac diffusion

- It was dynamic, with one diffusion encoding direction.
- The displacement field mimics a real human ventricle.

The sequence was a moment-compensated PGSE



Resulting images **without** and **with** moment-compensation

Demonstration

Acknowledgments

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