Minutes of the COSMIC Kick-off meeting

The 07/13/2016 @2:00PM at NeuroSpin

Attendees:

- CosmoStat (Jean-Luc STARCK, Florent SUREAU, Ming JIANG),
- NeuroSpin (Carole LAZARUS, Cécile LERMAN, Alexandre VIGNAUD, Antoine GRIGIS, Fabrice POUPON, Philippe CIUCIU)

Missing people: CosmoStat (Jérôme BOBIN and Sandrine PIRES) and NeuroSpin (Arthur COSTE)

Writer: Philippe CIUCIU

Version: 1.0

Date: 07/21/2016 (officially we will say that the project has been launched on Sept, 15 2016).

Round table during lunch: large panel of complementary skills represented across both teams

Carole's presentation: Compressed Sensing for high resolution MRI at 7T for clinical applications

- **I. Introduction: why and how?**
- **II. Our T2*w MR sequence "CS-GRE" and some first results**
- **III. Image quality issues**
- **IV. Conclusions and future work**

- **CS in MRI**: reduce MRI acquisition time by undersampling Fourier data. **N. Chauffert's PhD**: design of novel feasible sampling schemes which outperform classical sampling schemes
- For what kind of acquisitions are these samplings relevant? Long observation times-> T2* weighting (BOLD fMRI and Anatomical T2* imaging at high magnetic field). **Clinical interests of T2*w: neurodegenerative diseases hence an urging demand for High resolution.**
- OUR OBJECTIVE SO FAR: **T2* w anatomical imaging for high resolution MRI**
- Homemade adaptation of a T2* CS-GRE sequence (Gradient Recalled Echo) to perform arbitrary feasible trajectories. Main modifications from N. Chauffert's trajectories: make

the duration of trajectories compatible with the duration during which the MR signal is available hence around 40 ms maximum (currently Tobs=33.3 ms). Increase the number of segments (eg 64 at resolution 1024x1024), manage the echo time (time point at which the k-space center is traversed, currently TE= 30ms) and the direction of travel: from the outer part of the k-space to the inner part.

- Prospective compressed-sensing sequence has been implemented on a 7 Tesla scanner for T2* weighted imaging. Currently, we achieved a 16-fold acceleration factor for images of size 1024 x 1024: 16-fold acceleration i.e. TA=3.8 s instead of TA=1min04s in full sampling.
- Validation on ex-vivo baboon imaging, It works pretty well although there are still some reconstruction artifacts.
- We investigated several potential factors that may impact the image reconstruction quality: Sampling scheme, Acquisition (SNR, gradient errors), and the reconstruction procedure (\lambda setting, NFFT, Wavelet decomposition, Penalty type, minimization algorithm). So far, regridding +FFT looks much better than FISTA.
- As \lambda decreases the effective resolution increases but grid-like artifacts are appearing and masking the image.
- We emphasized a difference between reconstruction from retrospective and prospective undersampled data. Prospective CS means that the dare are really collected in a compressive manner whereas retrospective means that full k-space data have been acquired and that the undersampling mask corresponding to our trajectories has been applied afterwards on ~~y~~our computer.

Some specific points:

- Clarify that the **data are complex-valued in the k-space domain** even though the MR image should be real-valued. In practice, this means that we display the magnitude of the complex-valued reconstructed image, hence we're playing with wavelet decomposition of the real and imaginary parts at the reconstruction step. The phase is an important feature since it carries relevant information on tissue interfaces. See Alex's presentation for details and insight on why phase is non-zero.
- The experimental noise in the k-space is white and Gaussian
- Carole is currently investigating the putative origins of these artifacts.
- JL's advice: Try to reproduce on simulations (i.e. retrospective CS) the reconstruction artifacts shown in prospective CS. Introduce noise or errors over k-space trajectories to see whether the already existing MR image reconstruction artifacts are due to magnetic gradient errors. It's really important to understand these artifacts which are not ??
- Further directions:
  - Give up the L_1 penalization to promote better sparsity using the L_0 semi-norm

- Unsupervised setting of regularization parameter \lambda by considering its evolution over iterations (adjust its value with respect to the noise level i.e. for instance to 3 \sigma). We could also consider a \lambda per scale.
- Test other multiscale decompositions like curvelets …

- **Action: Carole is preparing data to be sent to Ming in an appropriate format while Ming is trying to adapt his code for complex-valued data/images.**

Ming's presentation: Radio Interferometry Image reconstruction

I. **Interferometry imaging**
II. **2D-1D sparse reconstruction and transient detection**
III. **Multi/Hyper spectral image restoration**
IV. **Conclusions**

Some important notes:

- The generative/observation model in interferometry is close to that of MRI
- Detection of slow transient in the universe is OK but low temporal resolution; it's more challenging to address the detection of fast transients.
- In that case, the masking operator (like the CS synthesis operator) becomes time-dependent.
- Inverse problem formulation and reconstruction using a constrained analysis approach (equivalent to synthesis approach for basis, !! no longer equivalent for frames). In the reconstruction process are injected both sparsity and non-negativity constraints.
- The formulation is mixed: 2D is space and 1D in time. Starlets for spatial decomposition, Haar wavelet for temporal decomposition.
- Condat-Vu's splitting method (2013) that is more accurate than Chambolle-Pock algorithm and avoids sub-iteration for the computation of the proximity operator
- Next point: hyperspectral data with source mixture model. The point spread function H is varying with the wave length; here the concept of channel is intrinsically related to a given wavelength. Hence, multiple channels -> multi-spectral imaging.
- SOA: BSS : 1/FastICA 2/ GMCA. Methods based on morphological diversity.
- Deconvolution outperforms BSS only.
- Deconvolution: ForWaRD: Fourier Wavelet Regularized Deconvolution. Motivation: it's easier to separate sources in the wavelet domain. The joint problem is no longer convex. Alternate optimization of a nice criterion involving L0 semi-norm, band-specific regularization parameters that are decreased over iterations…

- Very few literature on joint approaches
- Proposed approach: ForWaRD+GMCA = fGMCA
- Convincing results to detect transient sources.
- **fGMCA is an efficient method to solve jointly the BSS and the deconvolution problems.**

<u>Alex's presentation</u>: COSMIC: faisabilité expérimentale

MRI safety aspects related to the CS-MRI sequence under development. No specific risk with the MR sequence because the specific absorption ate and the peri-nervous stimulation are managed in real-time by the monitoring system installed on the MR scanner.

Why the MR measured signal (i.e. the free induction decay signal) is complex-valued and not real-valued: *L'environnement induit une évolution de la phase cumulée des spins par rapport à celle imposer par le synthétiseur. Cette information peut être mis profit pour connaitre la température, le flux, la susceptibilité magnétique des tissus,…*

<u>Fabrice's presentation</u>: COSMIC: Pathways towards online MR reconstruction at 7 Tesla: The Gadgetron solution

I. Real-time online imaging
II. Gadgetron

Some important notes:

- Current set-up actually deployed on the 3 Tesla Siemens scanner. The rt-MR system developed by Fabrice consists of getting the real time DICOM images from the reconstruction unit using a real-time export module to perform post-processing of functional and diffusion-weighted MR images.
- The parallelization is done using a home-made pthread library for multithreading and using MPI. Code written in the Ptk library in C++.
- Applications to the detection of evoked brain activity in fMRI, to tractography (search for structural connectivity in the brain) in dw-MRI data, and to relaxometry in quantitative MRI .
- Next step: replacement of the cluster by a multi-CPU machine with GPU card and interface with Gadgetron

- Gadgetron is an open-source framework for medical image reconstruction that supports C++, GPU programming for parallization, but also more evolved languages like Python and Matlab. The Gadgetron is a client/server application that allows a basic pipelining process. As regards the data, it supports the ISMRMRD format.
- Gadgetron's support part depends on the **MR system and may change even from one operating system to the next installed in a given scanner** (eg from VB17 to VE11). This server is not provided with the source codes.
- The communication between client and server is managed by the TCP/IP protocol.
- As regards, the Gadgetron development on MR Siemens systems, the Server available for downloadat https://www.mr-idea.com/
- Developmentof reconstruction «Gadgets» actually consist of writing either C++, CUDA, Python or Matlab (Prototype) code.
- It has been successfully deployed at NeuroSpin and tested using a C++ Gadget for thresholding images and using a Python gadget for relaxometry.
- **Important point: The 3T setup can be transposed to our 7T. The development of CS gadgets would achieve optimal performance if written in C++ and GPU.**

TO do list for Mid-September:

- **Jean-Luc**: Website creation and next Philippe will manage the admin and upgrade
- **Philippe**: Send the budget information to Jean-Luc (Ordre Statistique). Contact point at NeuroSpin: Emmanuelle Raboulin (Emmanuelle.raboulin@cea.fr).
- **Ming** : create a standalone package in Python for 2D reconstruction. Send your code by email. Send also your Python binding to the ondelette transformation class (C++) to Antoine
- **Carole**: produce data in the Fits format (Astronomy) compatible with Ming's code. As a first step, consider regridded data at the 1024x1024 spatial resolution.
- **Fabrice:** Download **the Sparse 2D C++ package** available on the Cosmostat website (focus on fast curvelets) and get fitsio too and start looking at acceleration issues (parallelization).
- **Carole, Philippe, Antoine & Fabrice:** Start investigating on how we could move our Matlab code to Python in the first place or to a C++ implementation in a second place for further parallelization in the near future.
- **Alex:** Investigate CPP issues for in-vivo imaging and get information for installing the boosted workstation (in use for parallel transmission at the 7 T scanner) as HP computer dedicated to on-line MR image reconstruction.