Chapter 4

Roadmap

In order to achieve the proposed objectives the next stages must be accomplished:

4.1 Generation of Data Bases

The main topics for this proposal will be studied on a theoretical framework but for evaluation and performance tasks we require a simplified but relevant data set.

4.1.1 Definition of Media

$2-D$ binary permeability channels will be used as target media. Aforementioned on preliminary sections, this kind of media are common in subsurface characterization and its description provide useful insights in the understanding of other subsurface properties. At the outset, we will work under a stationary assumption for the channels.

We will consider 3 kinds of simplified channels: a single channel model and two multichannel models with different level of complexity. These models have the form of $2-D$ discrete images representing a realization of a real channel. The realizations of the models are obtained using the standard *SGEMS* program (by *SNESIM* algorithm) and an additional preliminary training image provided by an expert.

4.1.2 TIs and RIs

From *SNESIM* algorithm we simulate realizations for each kind of channel. Each image have a size of 200 by 200 where each pixel with value 1 represents a high permeability position. Selected images will be used as realizations images (*RIs*) of the actual subsurface channels while others will play the role of training images (*TIs*).

4.2 Validation of Database

For the database validation we take into account the preservation of the patterns structure from the reference model and refuse realizations with discontinuities not present at reference model.

4.3 Preliminary Sampling Schemes

In both, *Sensing Placement* analysis and *sparse promoting* methods we require a subset of measurements as preliminary hard data. These preliminary sets work as constraints for *MPS* realizations and we will be obtained by sensing schemes including random, structured and random structured sampling. This sampling schemes will be implemented on *Matlab* framework.

4.4 Implementation of parser for MPS

In order to use *MPS* simulations for *NCS* algorithms we will implement an efficient parser to interact with *SGEMS* software. The proposed parser works on python and interact with *SGEMS* software and *Matlab* codes in a parallel framework.

4.5 Multi-Point Simulations

With the database, the preliminary samples and the developed parser we will simulate a set of 1000 images for each kind of channel. Each image have a size of 200 by 200 where each pixel with value 1 represents a high permeability position.

4.6 Statistics Estimation for MPS

For each set of images obtained from *MPS* we will estimate statistical information about the associated field. In the one side, for *OWP* problem we will use these sets as a source of patterns realizations to approximate joint and conditional *pdfs*. In the other side, for *NCS* these sets will work as a side information source of the spatial correlation for the regionalized variable.

4.7 System Modeling for NCS Algorithms

The basic considerations required to implement an appropriate *NCS* solver are:

- Whitening Processing: Current *NCS* theory was developed under the assumption of a model with white noise. Therefore, we must apply a whitening pre-processing to adapt the measured signal to the standard implementations of *NCS*.
- Basis Selection: We need to find an appropriate base to promote sparsity or compressibility. Previous work at our research team indicates that *DCT* and *Haar* transforms provide some interesting Basis to evaluate.

4.8 Implementation of NCS Algorithms

Based on l_1 *Magic* software, available for *Matlab* platform, we extend and implement *NCS* algorithms oriented to recovery the channelized structure of interest from low acquisition regimes.

- Dantzig Selector Solver: To implement and modify the classical *NCS* method with l_∞ norm regularization, with several definitions and approximations for covariance matrices.
- Basis Pursuit Denoising Solver: To implement and modify the classical *NCS* method with l_2 norm for the error minimization, with several definitions and approximations for covariance matrices.
- Total Variation Solver: To implement and modify approaches based on total variation regularization.

4.9 System Modeling for OWP Algorithms

To achieve this stage we need to develop the next tasks:

- OWP Formalization: We will analyze the optimal placement problem to the binary channelized structures and develop a theoretical framework to solve it.
- Optimal and Sub-Optimal Approaches: We will study the combinatorial solution associated to the optimal placement and some practical sub-optimal solutions based on iterative approaches.
- Experimental Entropy Estimation: We will estimate statistical information of channelized fields from simulations of *MPS* and training images.

4.10 Implementation of OWP Algorithms

Based on the Modeling framework developed for *OWP* we will develop the next solvers:

- Entropy Estimation by *MPS*: To implement and modify an empirical frequentist approach for entropy estimation from several *MPS* realizations.
- OWP-MPS Solver: To implement and integrate the statistical approach and the *OWP* solver in a solver to find (near)optimal sensing positions from low sampling acquisition regimes
- OWP-MPSe Solver: To implement and study a framework with re-simulation of *MPS* using previous *OWP* positions as hard data for a sequential *OWP* solver.

4.11 Time measurements and Performance Analysis

In order to assess the performance of developed solutions we will measure time required for the execution of each specific solver and we will study several indicators of overall performance from image reconstruction and entropy reduction.

4.12 Writing Preliminary manuscripts

Based on preliminary outcomes we will write the next proposals:

- Sampling selection and *MPS*, An information theoretic approach: We propose the writing of an initial paper of the application of optimal sensing placement theory to the characterization ob $2D$ binary channelized structures.
- Qualification Exam Report : We write this thesis proposal supported by previous work and potential contributions of our research topic.

4.13 Modification of NCS Algorithms

From preliminary results and the associated limitations of the classical constrains of *NCS* we propose the next stages to improve it performance:

- Joint TV-NCS Algorithms: To implement and modify approaches based on total variation regularization and to integrate this solver with *NCS* algorithms
- Variance Matrix Approximation Approach: We will implement approximated versions for the variance matrix obtained from *MPS* because its high dimensionality and complexity impose practical computational constrains. We will modify vari-

ance matrix estimation by the incorporation of additional constrains to the spatial correlation in the regionalized variables.

4.14 Modification of OWP Algorithms

From preliminary results of OWP we propose the next stages to improve its performance:

- Patterns Analysis from TI : We will modify our pattern analysis for *pdfs* estimation bypassing *MPS* by using the training images as a source of pattern occurrences on the channelized structure of interest. We will study several theories developed to address it problem.
- TIPS Formulation : We will implement a training image based pattern search *TIPS*.
- OWP-TIPS Approach : We will modify OWP to incorporate *TIPS* approach.

4.15 Formalization of Sampling Design and OWP

To address more general approaches of sampling design and OWP we propose the study of several theoretical well know regionalized fields and propose an indicator of media complexity:

- Resolvability Capacity RC: We will define an indicator of media complexity based on the entropy reduction provided by the incorporation of OWP positions to the measured knowledge of the field of interest.
- Gaussian Fields and OWP: We will study several common literature related with optimal sensor placement for continuous regionalized medias.
- Markov Chains Modeling for Binary Maps: We will study some models of spatial dependence based on Markov chains and to implement *Cliqué* based principles in our OWP framework.
- RC and Medias with Theoretic PDF: We will study the behavior of RC under some regionalized fields with theoretic well known *PDFs*.

4.16 Formulation of Near-Optimal Adaptive Compressed Sensing *NoACS*

We will study Adaptive Compressive Sensing (ACS) theory and implement some approaches oriented to merge our OWP principles and NCS based reconstruction solvers in a general framework. As our previous implementations are focused on near optimal estimations we will work on some Near Optimal Adaptive Compressive Sensing (*NoACS*) theoretical results and these possible use in our problem.

4.17 Implementation of Near-Optimal Adaptive Compressed Sensing

We will implement versions of $NoACS$ focused on $2-D$ binary signals by the modification of our preliminary versions of OWP and NCS.

4.18 Writing manuscripts for journals

We will to write a couple of additional publications and to assist some conferences related with our current and future work. In detail, we propose at least the next topics:

- Spatially correlated media characterization, Resolvability capacity as a complexity media indicator: We will to write a manuscript about our indicator of media complexity applied to the study of well known regionalized fields.
- Geological Binary Permeability Channels Images Reconstruction by Noisy Compressive Sensing: We will to write a manuscript consolidating our work of NCS for channelized structures.
- NoACS for Binary Permeability Channels: We propose the beginning of a manuscript incorporating the ideas developed on $NoACS$ applied to regionalized variables.

4.19 Gannt charts

To organize preliminary and future work we provide two separate schedules. The first one oriented to our preliminary work related with this thesis proposal and the second one oriented to the current and future work for the next years.

4.19.1 Preliminary Work

See figure 4.1

4.19.2 Future work

See figure 4.2

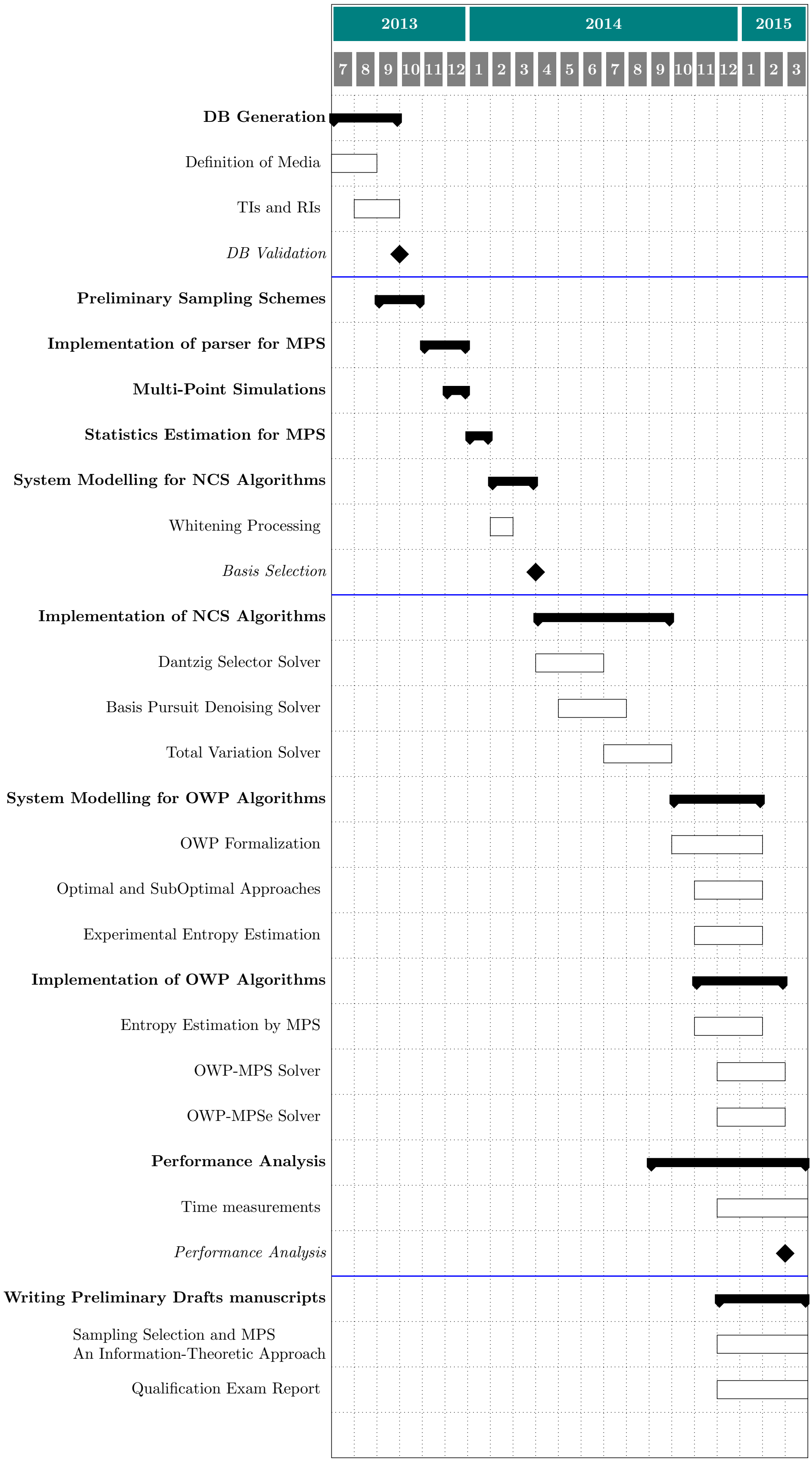

Figure 4.1: . Gannt Chart for Preliminary Work

Figure 4.2: . Gannt Chart for Current and Future Work

Chapter 5

Expected Outcomes

We have proposed the use of sensing design approaches and sparse promoting regularization methods to solve ill-posed problems of $2-D$ binary subsurface channels characterization. We address this problem by incorporating side information of spatial correlations from training images and *MPS*. We want to extend and to integrate previous outcomes from sparse representation and sensing theory.

Preliminary results give us some idea about the overall impact of proposed approaches. These approaches outperforms the *MPS* outcomes based on *SNESIM* algorithm. Classical *MPS* tools provide only a wide set of plausible realizations of the wanted signal focus on honoring patterns in a training image. However, the proposed methods are focused on recovery actual structure from low acquisition regimes providing a robust mechanism to estimate the field details with less variability.

A key expected contribution rely on the fusion of sensing theory and sparse recovery tools by an adaptive compressive sensing algorithm applied to the characterization of geological facies combined with the integration of geological prior information from the spatial correlation in the regionalized variables under analysis.

On the one side, for *OWP* approaches we propose the *pdf* estimation by the use of pattern occurrence analysis in the training images and from *MPS* realizations. The hypothesis regarding that *MPS* methods generates realizations preserving high order statistics from training images conditioned to hard data allowing an empirical approximation of the statistical information about the field.

On the other side, for *NCS* approaches we propose the use of a set of thousands of realizations of the field by *MPS* to calculate the statistical spatial correlation of the regionalized model. Therefore, we will to estimate covariance matrices. Thus, *MPS* is proposed as an excellent information source to estimate spatial dependence of the actual field conditioned to the *TI* and hard data. Additionally, several definitions of covariance approximations will be analyzed, in order to illustrate the relevance of a full or partial spatial interdependence characterization.

Conclusion

This research proposal focus on: (1) to find the sampling and reconstruction conditions required for the characterization of $2-D$ regionalized fields under the assumption of sparsity/compressibility and considering the incorporation of side information related with spatial dependence, (2) to improve previous outcomes in the reconstruction of $2-D$ signals for compressible generic signals, and (3) to reduce the variability of the *MPS* realizations providing an useful tool for exploration and characterization tasks. In order to achieve these topics, we propose the use of both sampling design methods and sparse promoting solvers in a novel near optimal adaptive compressive sensing approach. We will to adapt, improve and exploit prior information from training images in channelized structures characterization. Furthermore, we will to assess several covariance matrices approximations based on spatial constraints for *NCS*.

It is important to underline that there are not previous work that merge the topics covered in this proposal for the regionalized variables studied. In addition, there are not previous comprehensive analysis developed on this kind of media that exploit spatial constrains in the way proposed. Therefore, from the expected outcomes for this research we could ultimately lead to novel methods of *NoACS* exploiting spatial constrains of binary regionalized fields.

Although the proposed methods will be focused on $2-D$ binary channelized structures, the principles and application can be easily extended to other signals with spatial constraints. Depending of the achievement of proposed schedules we would to explore the applicability of our results in others signals at the final stages of this thesis.