dnarXiv

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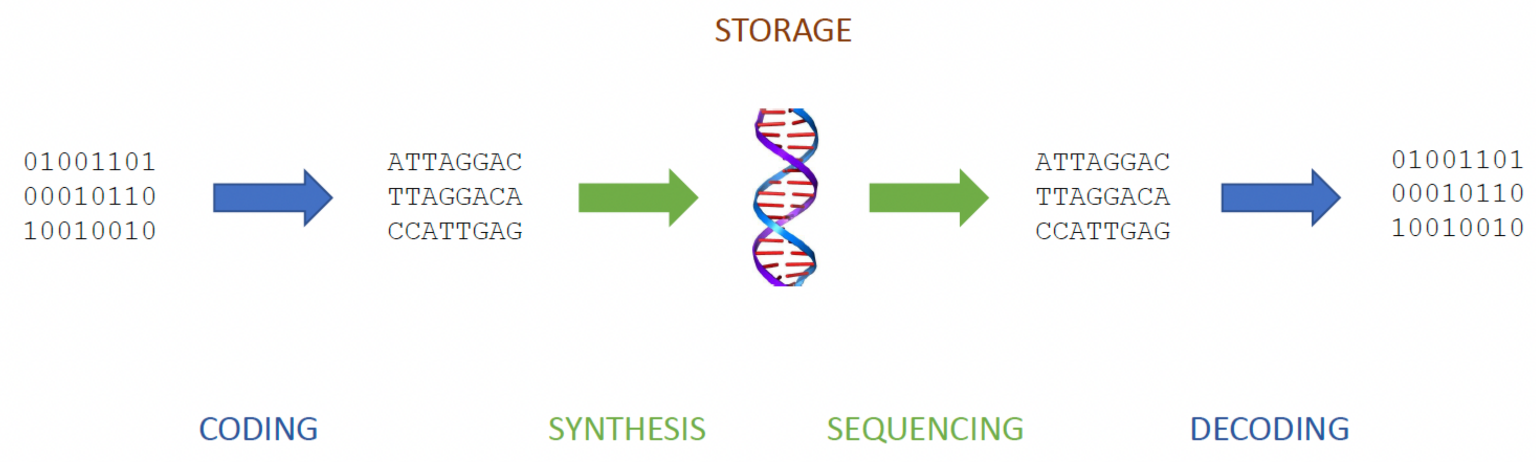
ABSTRACT

The aim of the dnarXiv project is to explore how to set up a complete DNA storage system. This kind of storage has the potential to become a major archive solution in the mid-to long term thanks to its capacity and durability.
The main issues addressed in this project are how such a system can be designed, what are the main bottlenecks, what are the impacts of the biotechnology constraints on the upstream and downstream numerical processing, how security aspects (confidentiality, integrity...) can be directly integrated into the biotechnology processes.



Biotechnologies: DNA synthesis and sequencing

This axis has investigated how DNA synthesis and nanopore sequencing technologies can be efficiently used for DNA storage, and has also identified constraints that need to be considered for efficient encoding and security methods.

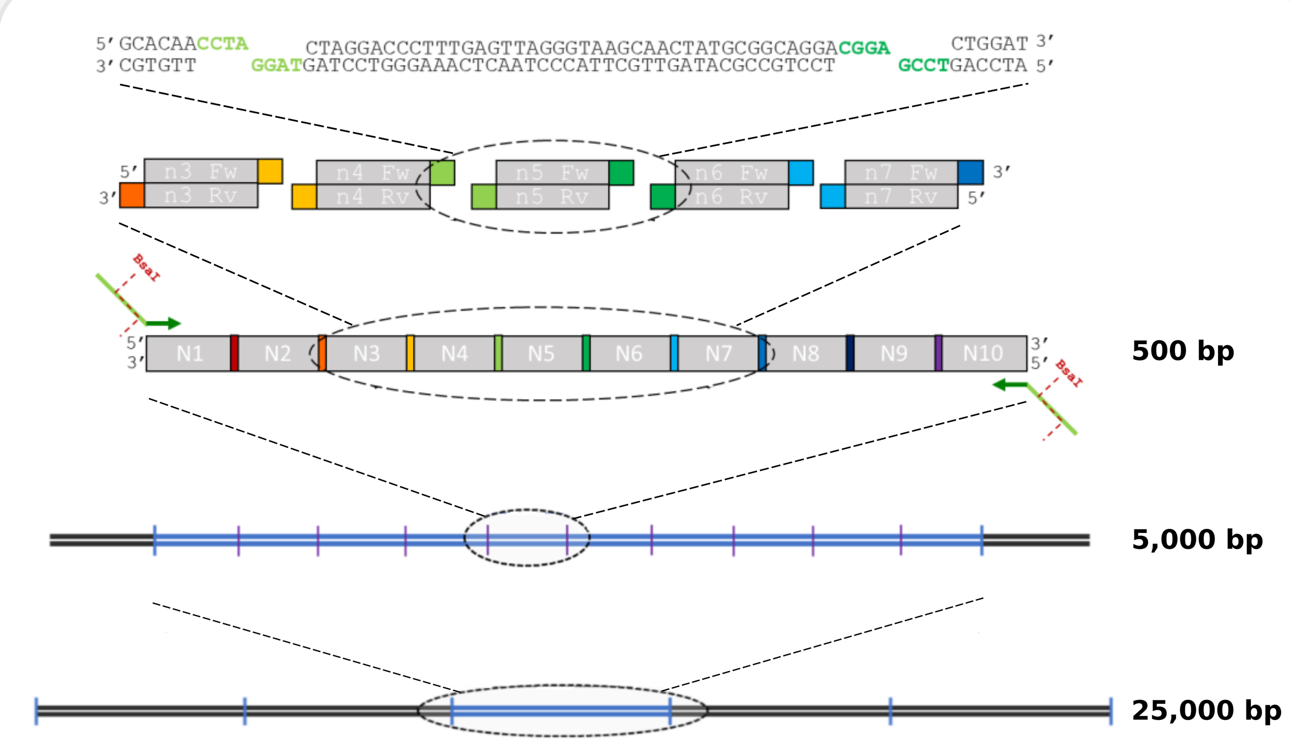
Contributions:

- Development of a pipeline to test the entire data storage and retrieval process from any document, with integrated simulators on the biotech parts

- Development of a fully *in vitro* protocol to generate very long double-stranded DNA molecule starting from commercially available short DNA blocks
Uses a seamless, ordered assembly in a single Golden Gate reaction

- Storage of the first articles of the Declaration of the Rights of Man and of the Citizen (4.2 ko text document) in a single DNA molecule, at an encoding rate of 1.34 bit/base

Sequence design for DNA assembly



Declaration of the Rights of Man and the Citizen of 1789

Error-correction codes

The biotechnological steps are a source of writing and reading errors that can compromise the reliability of the information. These errors consist of substitutions, but also insertions and deletions, which conventional error-correction solutions (Turbo, LDPC, etc.) cannot handle.
This axis error-correction codes are used to solve this problem at the cost of some redundancy in the written sequences.

Contributions:

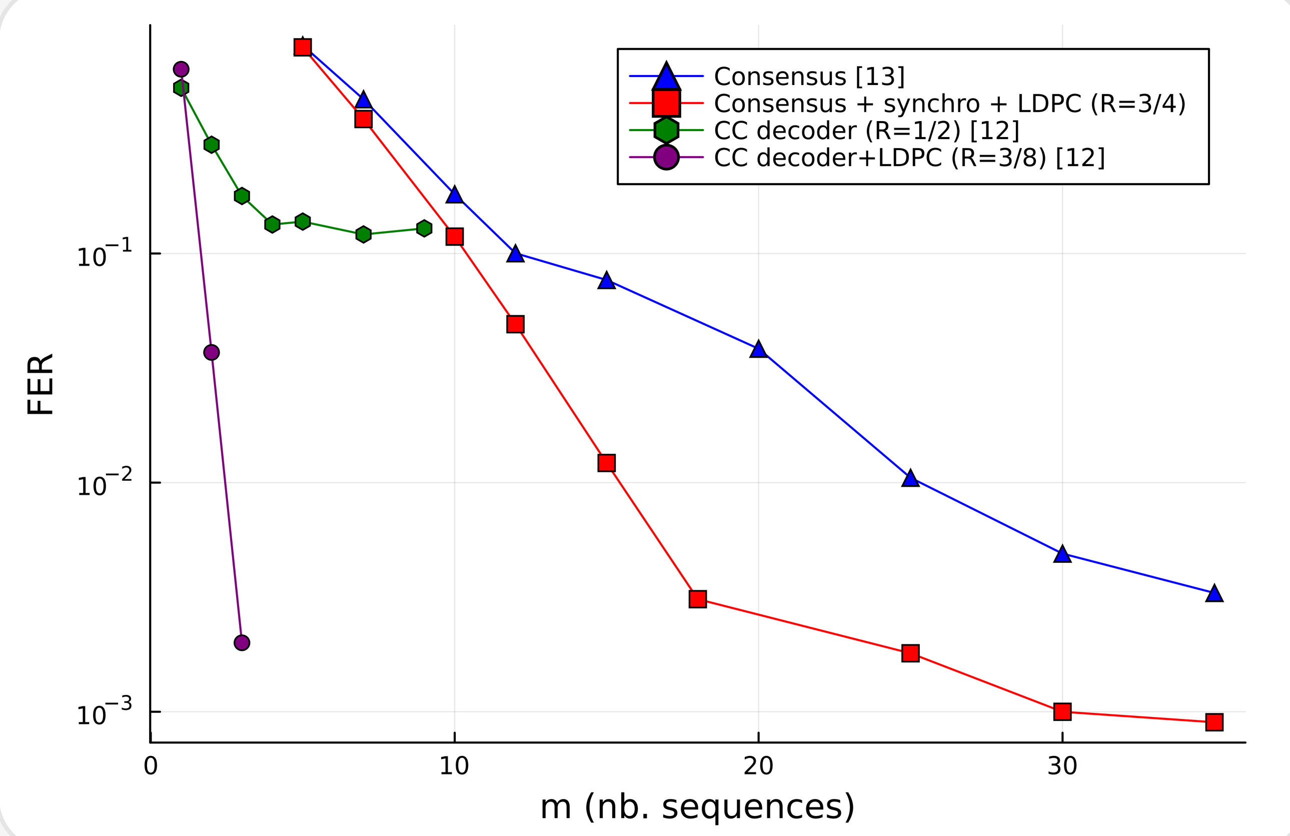
- Development of a statistical channel model to represent errors introduced by the DNA data storage process

- Efficient error-correction solution based on a convolutional code concatenated with LDPC codes
Low FER from a few output sequences at the cost of low coding rate

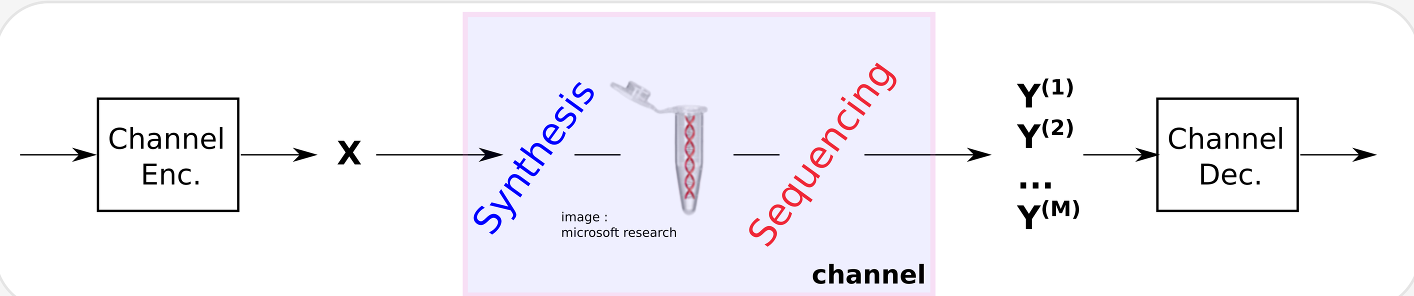
- Another solution based on a consensus algorithm and LDPC codes with a higher coding rate but requiring more sequences

PhD: Belaïd Hamoum, *DNA data storage algorithms and synchronization*

Frame Error Rate by number of sequences for different methods



Channel coding principle



Security

This axis has identified the risks to both the stored data and the DNA material, and has developed novel secure DNA storage mechanisms using biotechnologies for access control, confidentiality and authentication.

Contributions:

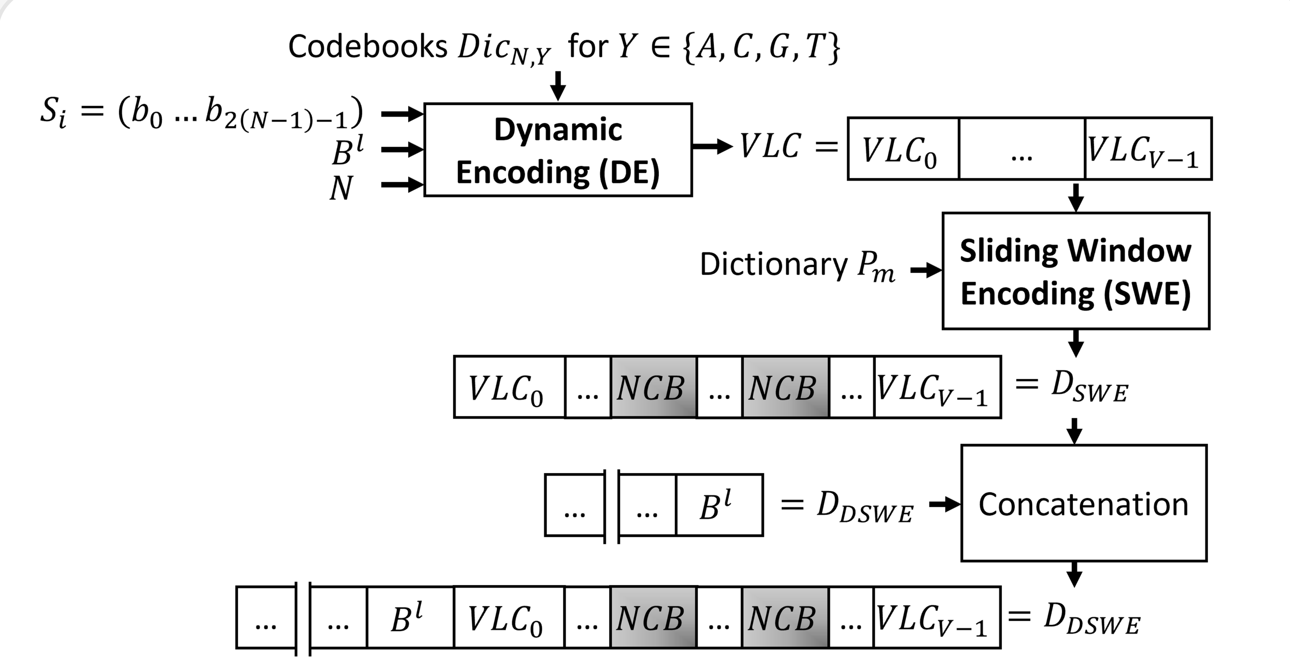
- In-depth analysis of risks to the DNA data storage chain

- Development of a Dynamic Sliding Window Encoding solution for binary data encrypted in DNA sequences, taking into account the specific constraints of data storage in DNA

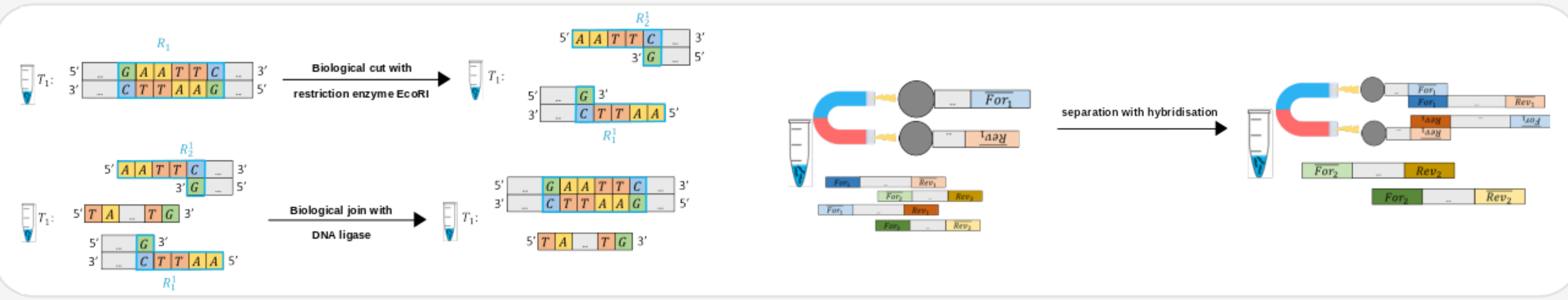
- Development and testing of a security solution based on biological operators
(biological manipulation of DNA to decipher data stored in DNA)

PhD: Chloé Berton, *Security of data stored on DNA molecules*
Internship: Jean Poulelaouen, *Testing error-correction codes solutions and adapting existing solutions for use with encrypted data encoding*
Internship: Hélène Gasnier, *Data compression and interaction with the DSWE encoding and development of a new corrector code method*

Dynamic Sliding Window Encoding for data storage on DNA under biological and indexing constraints



Rotation algorithm with biological operators



Publications:
- C. Berton, G. Coatrieux, D. Lavenier, S. Haddad, Dynamic sliding window encoding for data storage on DNA under biological and indexing constraints, EUSIPCO2023, 31st European Signal Processing Conference, Helsinki, Finland, September 2023
- B. Hamoum and E. Dupraz, "Channel Model and Decoder With Memory for DNA Data Storage With Nanopore Sequencing," in IEEE Access, vol. 11, pp. 52075-52087, 2023, doi: 10.1109/ACCESS.2023.3278975
- B. Hamoum, A. Ezzeddine, E. Dupraz, Synchronization algorithms from high-rate LDPC codes for DNA data storage, Rhodes, 24th International Conference on Digital Signal Processing, Island of Rhodes, Greece, June 2023
- D. Lavenier, DNA Storage: Synthesis and Sequencing Semiconductor Technologies, 68th Annual IEEE International Electron Devices Meeting, San Francisco, Dec. 2022
- B. Hamoum, E. Dupraz, L. Conde-Canencia, A DNA Data Storage Channel Model Trained on Genomic Data with Nanopore Sequencing, DSMM 2022, 1st International Conference on Data Storage in Molecular Media, 21-23 March 2022, virtual conference
- C. Berton, G. Coatrieux, D. Lavenier, A first proposal for secure data storage into DNA molecules compliant with biological constraints, DSMM 2022, 1st International Conference on Data Storage in Molecular Media, 21-23 March 2022, virtual conference
- O. Boullé, D. Lavenier, Experimental DNA storage platform, DSMM 2022, 1st International Conference on Data Storage in Molecular Media, 21-23 March 2022, virtual conference
- B. Hamoum, E. Dupraz, L. Conde-Canencia, D. Lavenier, Channel Model with Memory for DNA Data Storage with Nanopore Sequencing, 2021 11th International Symposium on Topics in Coding, ISTC 2021