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# Clustering strings with mutations using an expectation-maximization algorithm In the context of RNA structure prediction

Afaf Saaidi, Yann Ponty, Mireille Regnier

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### Outline

In comparative analysis, an RNA **structure** (a set of **base pairs** and **unpaired** nucleotides) is predicted from a set of RNA **variants** (similar sequences) under the assumption of the conservation of the structure during evolution.

The combination of RNA variants with Experimental data informing about the **local** (nucleotide) **structure** may lead to more accurate structure prediction.

The experimental protocol consists of mutating nucleotides likely to be 'unpaired'.

A simultaneous reading of RNA variants sequences that underwent the experimental mutation protocol lead to the following issue:

**How to cluster 'mutated' substrings of similar parent strings such that each substring is correctly assigned to its parent string?**

We developed an **Expectation Maximization** algorithm that uses Mutational profiles (mutation distributions) to assign the substrings to their strings of origin.

### RNA structure

- ▶ RNA is key to understand many biological processes (As in viral RNA).
- ▶ RNA maintains a stable **functional structure** during its **evolution**.
- ▶ Computational methods allow to have accurate 2D structure predictions ( $PPV \approx 75\%$ ), less accurate predictions for long RNA.
- ▶ + Experimental probing data informing about **local** (nucleotide) structure improve predictions.

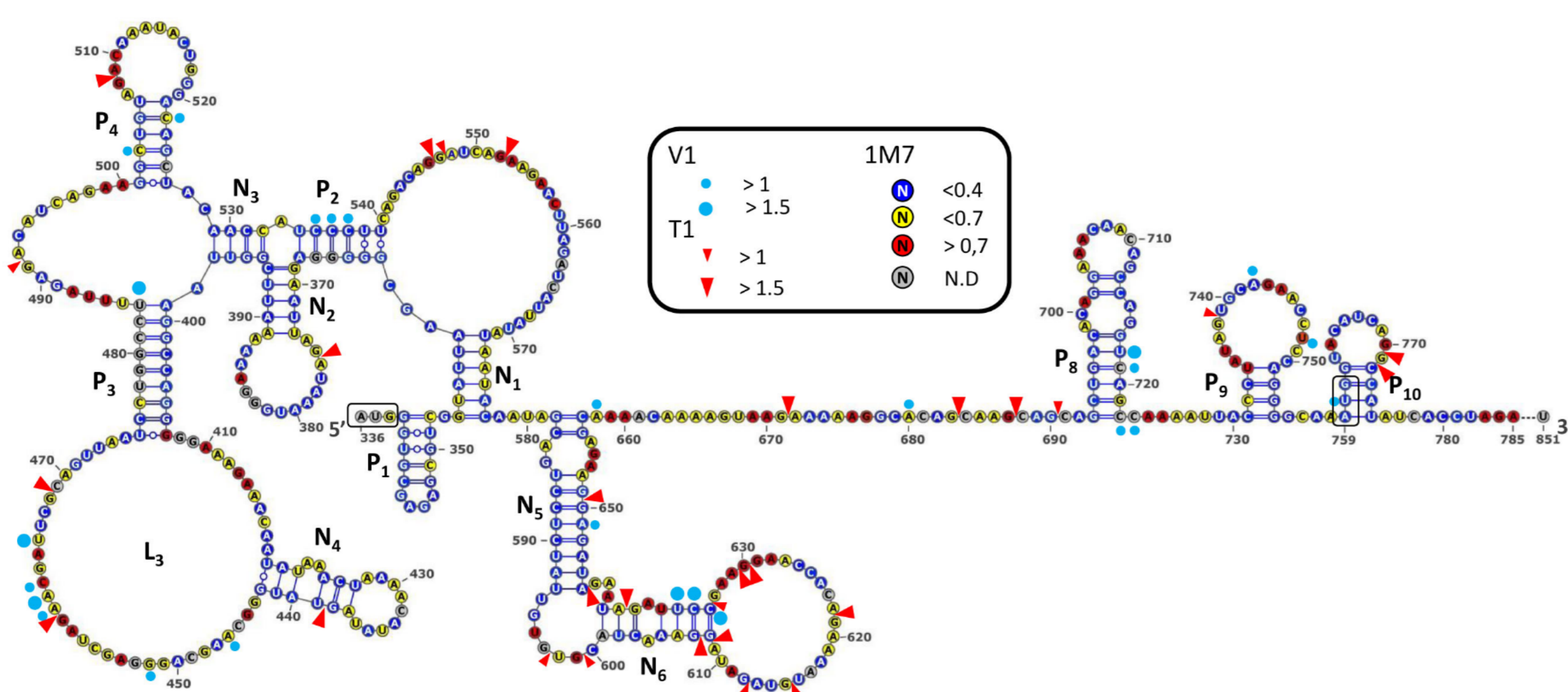
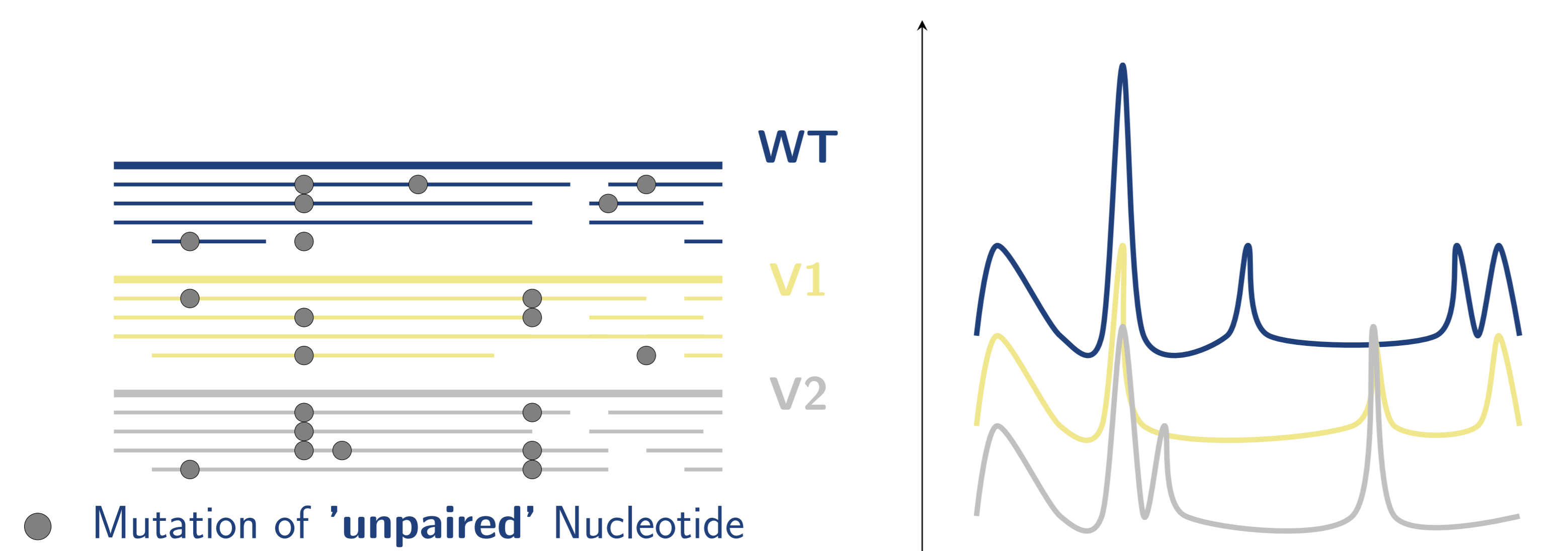


Figure 1: RNA secondary structure model of the HIV1 Gag-IRES with the projection of Experimental probing data [1]

### Mutational profiles

A set of 3 **similar** strings with symbols in the Alphabet  $\Sigma = \{A, C, G, U\}$

	P <sub>1</sub>	P <sub>2</sub>	P <sub>3</sub>	P <sub>4</sub>	P <sub>5</sub>	P <sub>6</sub>	P <sub>7</sub>	P <sub>8</sub>	P <sub>9</sub>	P <sub>10</sub>
WT	C	G	A	C	G	C	U	C	U	U
V <sub>1</sub>	C	G	A	C	U	C	A	C	U	U
V <sub>2</sub>	U	A	A	C	G	C	U	C	U	U



### The assignment problem

Given the substring  $r_1$  **CAAC**:

Variant V	Locus ( $r_1, V$ )	Distance( $r_1, V$ )
WT	$p_1$	$\underline{1}$
V <sub>1</sub>	$p_1$	$\underline{1}$
V <sub>2</sub>	$p_1$	$\underline{1}$

**Q.:** Since  $r_1$  is showing the same nucleotide distance to all the variants, what is its string of origin ?

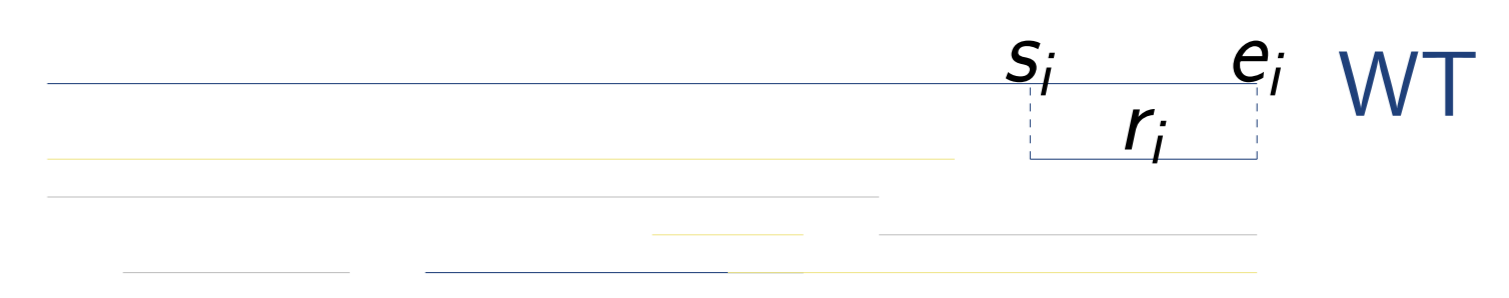
→ **Mutational Profiles** with the **Expectation Maximization** algorithm.

### The objective

**Our goal is to resolve the assignment problem: given substrings derived from a set of similar sequences and where structural mutations happen, what are the original strings of each substring?**

### Key idea of using the Expectation Maximization algorithm

- ▶ **Circular dependency** between the mutational profiles and the assignments of substrings [2]  
→ Performs a **joint inference** of the **mutational profile** and the **assignment**



$$L(\theta; x, z) = \prod_{i=1}^r \prod_{j=1}^V \left[ \frac{f(x_i; M_j)}{V} \right]^{1_{z_i=j}}$$

- ▶  $\theta$ : **Mutation probabilities**  $\theta = \{M_j\}_{j=1}^V$
- ▶ **M**: **Mutational profile**  $M_j : [1, n] \times \{m, \bar{m}\} \rightarrow [0, 1]$  for  $v_j$
- ▶ **Density function**:

$$f(x_i; M_j) = \prod_{k \in [s_i, e_i]} M_j(k, x_{i, k-s_i})$$

- ▶ **Assignment probability**:

$$T_{j,i}^{(t)} := P(Z_i = j | X_i = x_i; \theta^{(t)}) = \frac{f(x_i; M_j^{(t)})}{\sum_{j'=1}^V f(x_i; M_{j'}^{(t)})}$$

### Steps on EM for the substrings assignment

1. **Initialization**: For each substring  $j$  choose the initial estimates  $M_j(k, c)^{(0)}$ ,  $c \in N$ , and compute the initial loglikelihood.
2. **E step**: Compute the density function  $f(x_i; M_j^{(t)})$ .
3. **M step**: Update  $T_{j,i}$  then, compute the new estimates  $M_j(k, c)^{(t+1)}$ ,  $c \in N = \{m, \bar{m}\}$ .
4. Iterate until convergence.

### Results on simulated substrings with mutation

Set	Iteration	ET(s)	EM-assignment		TMAP (MapQ ≤ 1)	
			correct	incorrect	correct	incorrect
1	1		<b>292</b>	2144	<b>239</b>	148
	2		295	2141		
	117		1444	992		
	1000	5713.5	<b>1538</b>	898		
2	1		<b>983</b>	1243	<b>215</b>	2
	2		1096	1130		
	295		1122	1104		
	1000	5537.8	<b>1138</b>	1088		

### References

- [1] J. Deforges, S. de Breyne, M. Ameur, N. Ulryck, N. Chamond, A. Saaidi, Y. Ponty, T. Ohlmann, and B. Sargueil. Two ribosome recruitment sites direct multiple translation events within HIV1 Gag. *Nucleic Acids Research*, 2017.
- [2] Afaf Saaidi. Multi-dimensional probing for rna secondary structure(s) prediction. *Ph.D. thesis*, Chap.6, 2018.

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