Finding Approximate Tandem Repeats in Genomic Sequences

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Genomic sequences tend to contain consecutive copies of patterns known as *tandem repeats* (TR). These occur due to DNA repair systems and other mechanisms, not all fully understood. Tandem repeats have proven useful as markers in genetic analysis due to the high degree of polymorphism observed in their number (e.g. for DNA fingerprinting applications [2]). Sometimes, such repeats are known to be the cause of a disease like in the case of Fragile-X syndrome and Huntington's disease.

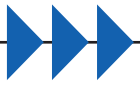
A perfect tandem repeat is defined as a string of nucleotides, which is repeated consecutively at least twice. Many $O(n \cdot \log n)$ algorithms have been presented for finding perfect tandem repeats. However, in practice, mutations, translocations, and other biological events render the copies imperfect. This often results in *approximate tandem repeats* (ATR) defined as a string of nucleotides repeated consecutively at least twice such that, with sufficiently high probability, they originated from the same string. Finding ATRs in a genome is clearly a harder task than finding perfect repeats and has been addressed several times. The IBM bioinformatics group, have presented the best results so far [3] by altering their own TEIRESIAS pattern-finding algorithm.

The algorithm we present herein has *screening* and *verification* stages. In the screening stage, the possibility is evaluated of finding an ATR of certain length, at a certain position, with sufficiently high probability. In the *verification* stage, an alignment for each resulting candidate is generated and subsequently accepted or rejected as an ATR according to statistical criteria.

The *screening stage* uses a statistical model in which we consider matching two adjacent copies of a pattern of length t as a sequence of t independent Bernoulli trials. We replace the search for k contiguous successful nucleotide matches suggested by Benson [1] with a less stringent approach, as follows.

Consider a comparison to be a series of w independent Bernoulli trials, where w is a function of the pattern length t. Each trial compares two aligned nucleotides and the comparison passes if at least $l(w)$ such trials succeed. Three comparisons of length w are performed for each starting offset i, where $O \le i \le t - w(t)$, to account for a single insertion, deletion or no-change at location i. We define the success list $S_t(i)$ of i with respect to the pattern length t to be the set of integers $j \in [i, i + t - w]$ for which the comparison starting at position j succeeded. The cardinality of $S_t(i)$ is called the score of i with respect to t.

In order for a position to pass the screening and become a candidate for verification, it has



to satisfy several statistical criteria regarding the P-value of its score and a *valid* distribution of successful comparisons. We perform these comparisons on an entire genome of size n for all pattern lengths up to some T_{max} in time $O(T_{max} \cdot n)$. This complexity is achieved because, instead of computing each comparison separately, they are computed incrementally while sliding over the genome.

The *verification stage*, when given a candidate ATR starting at position i with pattern length t, generates an alignment between the pattern starting at position i and the one starting at position $i+t$, both of length t, using a predetermined scoring system. If the alignment score is over a threshold, which depends on the scoring system, then the candidate is accepted as an ATR.

Results

The algorithm presented herein, aside of having a linear time complexity in genome size n when fixing T_{max}, also performs well on real examples. When running over the yeast chromosome 1, which is the same genomic sequence used by IBM bioinformatics group to establish their results, using the same scoring system for verification as they did, and finding ATRs with length ranging from 10 to 300, the following facts emerge:

- Our algorithm found more than twice as many ATRs as was previously reported, finding also all the ones known before.
- A low rate of false positive candidates occurs during the screening stage (~3%). Consequently, the running time was less than 1% of the time reported by the IBM group, on a machine with no greater power.
- Our algorithm is parameter-free and does not require additional input from the user, aside of biological data, sequences, and a desired scoring system for alignment.

References

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