INFBIOx121 - Algorithms module Sequence mapping

Autumn 2017







Gigsaw from University of Dundee

- Four people in each group
- Set up the reference sequence: both forward and reverse (reverse complement)
- Each person takes 10 reads. Notice that reads are reverse complemented on the back. So use the side that is most convenient.
- Map individually in parallel: two persons can map to forward and two to reverse.
- Then combine the reads to variant call together.
- In 10 mins, I want to know what you have found out

Gigsaw thoughts....

- Did you find some other interesting positions?
- Did all reads map perfectly
- Could this be a diploid organism?
- What if you had only had:
 - one of the references?
 - one side of the read?



MAPPING WITH BWA

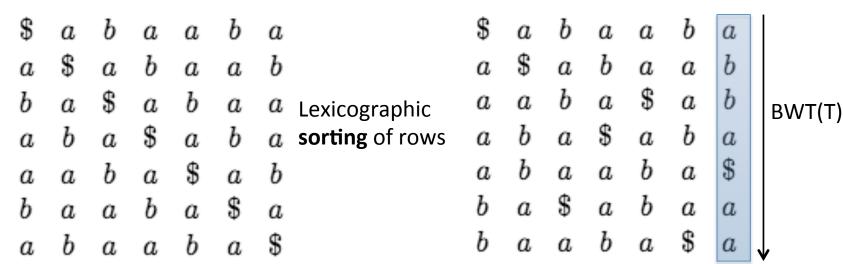
Why mapping?

- The biggest difference with Sanger
 - we did not design and use primers for sequence amplification
 - we sonicated
 - >> we do not know where the reads "originate" from
- For each read
 - we need to determine its likely origin
 - how likely it is that we have correctly identified its origin

http://www.cs.jhu.edu/~langmea/resources/bwt_fm.pdf

- The Burrows-Wheeler Transform (BWT) is a way of permuting the characters of a string T into another string BWT (T)
- For example for T = abaaba\$
- \$ defined to be a character that does not appear elsewhere in T and which is lexicographically prior to all other characters
- The rotations of T

Burrows-Wheeler Matrix BW M(T)



BWT(T) = abba\$aa

Relationship to suffix array

- Suffix array = sorted array of all suffixes of a string
- T = abaaba\$

All suffixes of T		Sorted suffixes	Matching order					
0	a b a a b a \$	6 \$	BWM:	SA:	Suffixes	given	by	SA:
1	baaba\$	5 a\$	\$abaaba	6	\$			
2	aaba\$	2 a a b a \$	<u>a</u> \$abaab	5	a\$			
3	a b a \$	3 a b a \$	<u>aaba\$</u> ab	2	aaba\$			
4	ba\$	O abaaba\$	<u>aba\$</u> aba	3	aba\$			
5	a \$	4 ba\$	abaaba\$	0	abaaba\$			
6	\$	1 baaba\$	<u>ba\$</u> abaa	4	ba\$			
J	т	1 0 0 0 0 Q	<u>baaba\$</u> a	1	baaba\$			

The LF mapping property of the BWT

- BWT(abaaba\$) = abba\$aa
- Seem like we have lost which a in BWT(T) corresponds to which a in T
- BUT we have not thanks to an important property of the BWT called LF mapping

$$T = a_0 b_0 a_1 a_2 b_1 a_3$$
\$

The subscript corresponds to the number of times the character has previously been seen in T

We call the subscript the rank \$ does not require rank as occurs only once

The LF mapping states: the ith occurrence of a character c in the **L**ast column has the same rank as the ith occurrence of c in the **F**irst column

We will not prove why!!

How do we reverse BWT? Useful for compression

We re-rank them:

Skipped

F	L	rank	F	L	rank
\$	a	0	Start with \$ \$	a	0
a	b	0	a	b	0
a	b	1	a	b	1
a	a	1	a	a	1
a	\$	0	a	\$	0
b	a	2	b	a	2
b	a	3	b	a	3

The LF mapping states: the ith occurrence of a character c in the last column has the same rank as the ith occurrence of c in the first column

Rows are rotations of T so last col of the first row contains the character to left of \$ in T: a

Rank array tells us this is a with rank 0

How do we get the character to the left of a_0 ?

We can do this if we know the row that begins with a₀

The LF tells us which row begins with a₀: the first row containing an "a"

Assuming first row is 0, we visit rows: 0, 1, 5, 3, 2, 6, 4 $\longrightarrow a_3b_1a_1a_2b_0a_0$ \$

Reversible means useful for compression

^{*} Before we ranked according how many times occurred previously in Tie Tranking

^{*} Now we re-rank according to how many times previouly seen in BWT(T) ie B ranking

FM index – key to searching a string

- Ferragina and Manzini: BWT can be used as a space-efficient index of T
- Searching for occurrences of P = aba
- The BWM is sorted, so any rows having P as a prefix will be consecutive

First find the rows beginning with the shortest **suffix** of P i.e. "a" >> rows 1,2,3 and 4 suffix of P i.e. "ba" rankawith b0 and b1 3

a

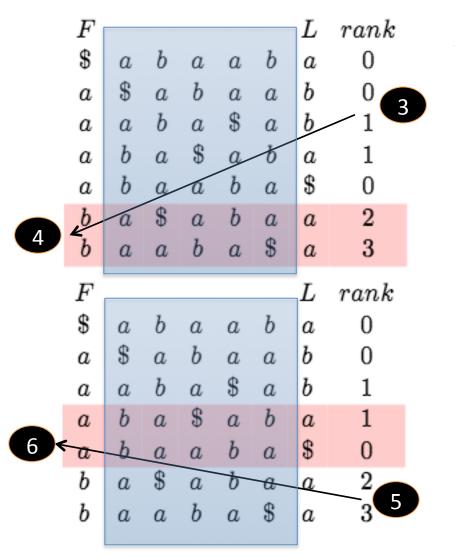
Second find all rows begin with the **next** longest

>> these are rows 1 and 2 (rows are rotations of T)

The LF mapping and rank array tell us which rows have "ba" as a prefix: rows beginning

The LF mapping states: the ith occurrence of a character c in the last column has the same rank as the ith occurrence of c in the first column

Searching T



The LF mapping and rank array tell us which rows have "ba" as a prefix: row begining with b0 and b1

Occurrences of "ba" are preceded by a2 and a3

Backward matching: apply LF mapping repeatedly to find range of rows prefixed by successively longer proper suffixes of P until range is empty or run out of suffixes

With only 3 backward matching (LF mapping and rotations) operations we have found the rows prefixed with occurrences of "aba"

Looking up offsets

So far we have discussed how to use the FM Index to determine whether and how many times a substring P occurs within T, but we have not discussed how to find where P occurs, i.e. the substring's offset into T.

If our index included the suffix array SA(T), we could simply look this up in SA(T). For example, here was the range we ended up with after searching for P = aba within BWT(abaaba\$):

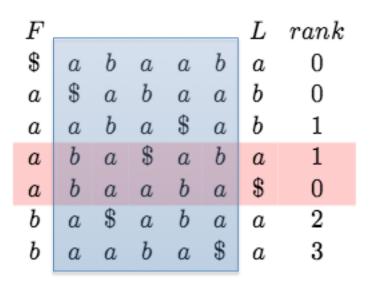
SA and BWM have a corresponding order

										•	U		
F						L	SA(T)	BWM:	SA:	Suffixes	given	bу	SA:
\$	a	b	a	a	b	a	6	\$abaaba	6	\$			
a	\$	a	b	a	a	b	5	a\$abaab	5	a\$			
a	a	b	a	\$	a	b	2	aaba\$ab	2	aaba\$			
a	b	a	\$	a	b	a	3	aba\$aba	3	aba\$			
a	b	a	a	b	a	\$	0	abaaba\$	0	abaaba\$			
b	a	\$	a	b	a	a	4	ba\$abaa	4	ba\$			
b	a	a	b	a	\$	a	1	baaba\$a	1	baaba\$			
	_												

SA(T) tells us these matches occurred at T offsets 0 and 3.

T=abaaba 012345

Maybe that did not seem impressive.....



I could have found the offsets of "aba" in T. Yes, BUT:

- either you then scan T with "aba" >> exhausitve search
- **or** you have to store the whole BWM matrix

When the string you are searching is 3 billion bases long that means:

- either you check for a match at every 3 bn positions
- or you need to store a matrix that is 3bn x 3bn

If you use the BWT and suffix array:

- You only need to store the first and last columns of the BWM (not the blue section)
- You need to do X backward matching operations to locate a string of length X

There are many optimisation to:

- Decrease space requirements
- Decrease time requirements
- Allow for mismatches

Application to read mapping

- You need to build an index of the genome you wish to search
- Reads are 100 bp long
- But, the longer the string searched for the longer the search time (longer backtracking), thus an advantage to search with a shorter string.
- There are 4 different nucleotides and 3.0E09 bases of genome
 - -4**16 = 4.0E09
 - -4**17 = 17.0E09
- Assuming complex sequence, 16 to 17 bp should be enough for a unique match
- BUT
 - variation in sample relative to reference
 - base call errors
 - THUS 17 bp search string is not enough
- BWA searches with a "seed" of 32 and allows 2 differences in the seed
- Reads with seed matches are aligned using Smith-Waterman

Mapping exercise with BWA

- Log into the virtual machine
- Open the exercise file in a text editor:
 algorithms_mappingExercise.bash
- Open a terminal and carry out the exercise