

# Exercise sheet 10: Introduction to Mapping

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## Exercise 1

**Question 1A** Extract the Burrows-Wheeler Transform  $B(S)$  of  $S = TGGTGGTTGA\$$ .

**Solution**  $B(S) = AGTTTGGT\$GG$

i	SA[i]	SA[i]-th suffix	Rotation	Last column
1	11	\$	\$TGGTGGTTGA	A
2	10	A\$	A\$TGGTGGTTG	G
3	9	GA\$	GA\$TGGTGGTT	T
4	2	GGTGGTTGA\$	GGTGGTTGA\$T	T
5	5	GGTTGA\$	GGTTGA\$TGGT	T
6	3	GTGGTTGA\$	GTGGTTGA\$TG	G
7	6	GTTGA\$	GTTGA\$TGGTG	G
8	8	TGA\$	TGA\$TGGTGGT	T
9	1	TGGTGGTTGA\$	TGGTGGTTGA\$	\$
10	4	TGGTTGA\$	TGGTTGA\$TGG	G
11	7	TTGA\$	TTGA\$TGGTGG	G

**Question 1B** Invert the Burrows-Wheeler-Transform  $B(S) = TCAACT\$AA$  to obtain S.

**Hint 1** You can get the first column  $F(S)$  of the Burrows Wheeler Matrix via counting and sorting the letters since it has a very predictable structure.

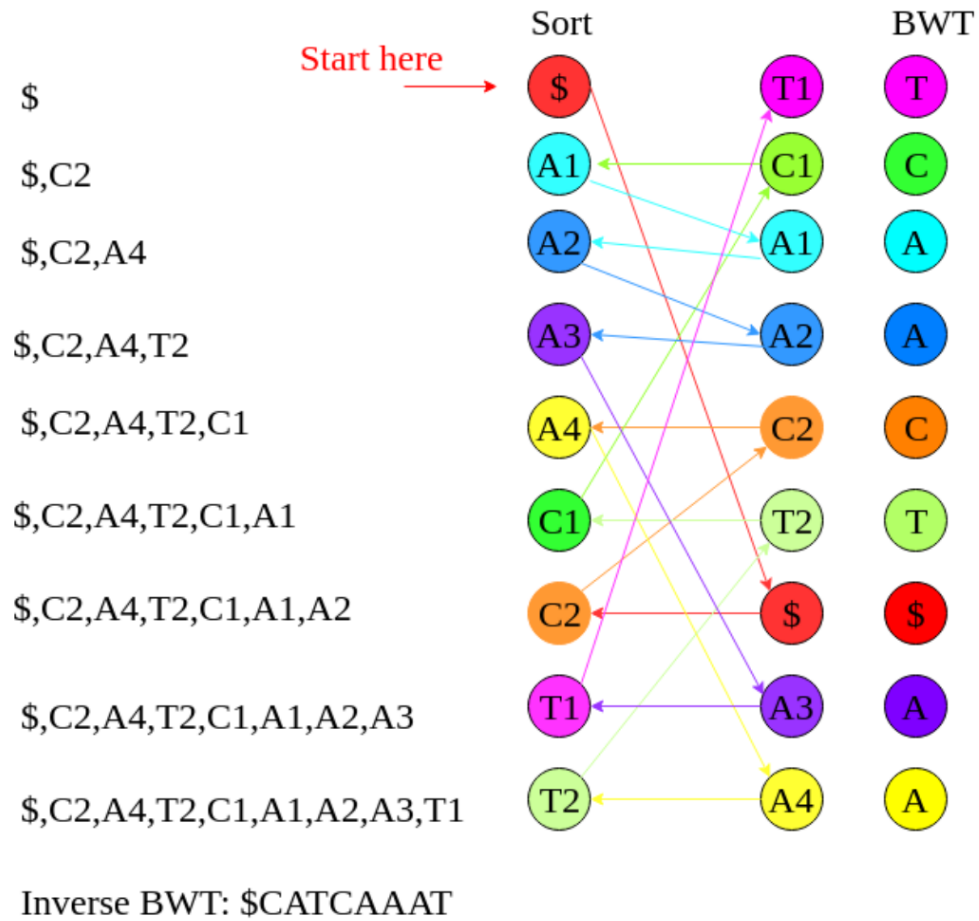
$$F(S) = \$AAAACCTT$$

**Hint 2** Use the last-first mapping to assign indices to the corresponding letters in the first  $F(S)$  and the last column  $B(S)$

$$F(S) = \$_1 A_1 A_2 A_3 A_4 C_1 C_2 T_3 T_4$$

$$B(S) = T_1 C_1 A_1 A_2 C_2 T_2 \$_1 A_3 A_4$$

**Solution 1**

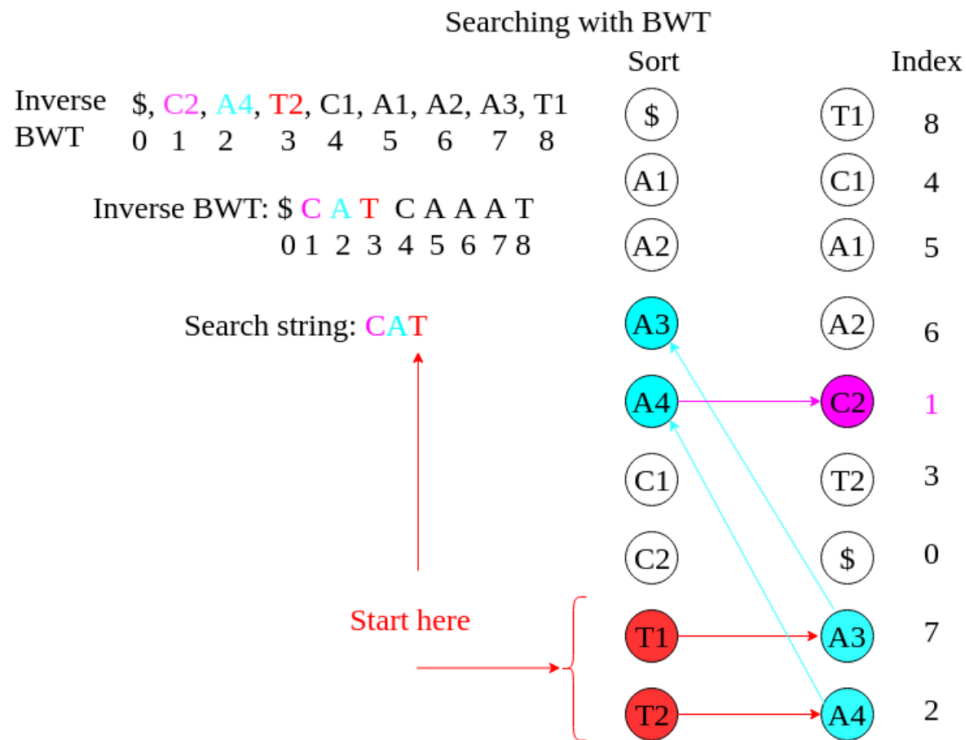


**Solution 2** Step-by-step method:



**Question 1C** Search for  $CAT$  in  $B(S) = TCAACT\$AA$ .

**Solution**



## Exercise 2

Read the publication on the bwa-mem aligner at <https://arxiv.org/abs/1303.3997> and pay particular attention to the re-seeding and chaining features of the algorithm. Now consider a read  $R = CCCCCGTTTT$  and a reference genome  $T = \dots CCCCCATTTT \dots CCCCCGA \dots AGTTTT \dots$  and explain step-by-step how re-seeding and chaining let bwa-mem let recover the correct best alignment of  $R$  to  $T$ .

**Question 2A** What are the original SMEMs that get generated?

**Solution** The original MEMs are CCCCCG and GTTTT.

**Question 2B** Would these SMEMs lead to discovery of the best possible alignment?

**Solution** No, because it would not lead to a best possible match in the reference genome. The current seeds are too specific and we may miss the seeds that lead to the best mapping (CCC- CATTTT), therefore we need to reseed.

**Question 2C** Which shortened new SMEMs are discovered with re-seeding (assume re-seeding gets performed despite the below-threshold length of the SMEMs)?

**Solution** Re-seeding around the central base of each MEM leads to discovery of CCCC and TTTT (both occur once more often than the originals).

**Question 2D** What is the effect of chaining of colinear seeds?

**Solution** The two new seeds are colinear on R and T , and can be merged into a chain, so only one local alignment has to be performed.

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## Exercise 3 - Programming assignment

Programming assignments are available via Github Classroom and contain automatic tests.

We recommend doing these assignments since they will help you to further understand this topic.

Access the Github Classroom link: Programming Assignment: Sheet 10.

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