# ScarMapper User Guide

ScarMapper is a Python program designed to analyze the DNA repair products at targeted loci that result from double strand breaks. In this case the double strand breaks are induced using CRISPR. This method has advantages over other methods such as CRISPResso2 and HiFiBR because it does not depend on aligning the sequence reads to each other when creating a consensus or to a reference to identify INDELS.

## Prerequisites for running ScarMapper

1. Linux OS, tested on RHEL 7.x, Scientific Linux 7.x, and CentOS 7.x. Will possibly run on a Mac OS, although it has not been tested. Will not run on Windows because ScarMapper uses Pysam to parse the reference FASTA file.
2. Ideally ≥32 Gb RAM. The amount of RAM depends on the number of reads being processed. This amount will allow processing of a FASTQ file containing ~15 million read pairs. The minimum recommended amount of RAM is 24 Gb. This will allow processing of ~8 million read pairs. The RAM does not scale equally with the number of reads.
3. >2 CPUs or threads. Processes one library per CPU/thread in parallel. The number of parallel jobs possible is CPUs or threads minus 1.
4. The minimum available drive space required is approximately 500 Mb. This does not include the space required for the FASTQ files.
5. Python ≥3.5
   1. Python ≥3.6 recommended
6. Python packages in no particular order, latest version of each
   1. scipy
   2. natsort
   3. pysam
   4. python-magic
   5. pathos
   6. numpy
   7. python-Levenshtein
   8. cython
   9. setuptools

## Installation

1. Download or clone ScarMapper from GitHub (https://github.com/pkMyt1/ScarMapper.git) to a location you have read/write access. Do not attempt to install using the setup.py file.
2. Test installation by moving to the ScarMapper directory and executing <python3 scarmapper.py> (without the <>). You should get the error message below.
   1. usage: scarmapper.py [-h] --options\_file OPTIONS\_FILE  
       scarmapper.py: error: the following arguments are required: --options\_file

## Required Files

ScarMapper requires the files listed below. Examples of the Master Index file and the Targets file can be found in the docs folder of ScarMapper. The formats and contents of each of these is discussed later.

1. Genome Reference Sequence in FASTA format.
   1. Obtain a reference genome of your choice such as GRCh38 or GRCm38. Make sure you also have the index file. If one was not available to download you will need to create it with Samtools. Place these files in a directory you have access to.
2. Sample Manifest File
   1. Tab delimited text file. The excel template (ScarMapper\_Sample\_Manifest.xlsx) is found in the docs folder. As a minimum, columns A through E are required for ScarMapper. Either copy and paste those columns into a text editor or export the sheet from the excel file as a tab delimited csv file. The rows that begin with a # are treated as a comment line.
3. Paired end FASTQ files.
   1. Place these somewhere you have read access to. ScarMapper is designed to use compressed, paired end, multiplexed FASTQ files as input. Uncompressed files or a demultiplexed FASTQ file will also work.
4. Master Index File.
   1. This file is derived by copying the first three columns from the sheet in the **ScarMapper\_Sample\_Manifest.xlsx** file that corresponds to your sequencing platform and sequencing design. The file should be saved as a tab delimited text file. The table below shows the layout for Illumina dual indexing.

|  |  |  |
| --- | --- | --- |
| **# Index\_ID** | **Forward (D7s)** | **Reverse (D5s)** |
| D501+D701 | ATTACTCG | TATAGCCT |

1. Targets File
   1. This is a tab delimited text file. File ScarMapper\_Targets.csv, found in the docs folder, shows how the file is to be laid out. The first row must start with a #. Place this file in a location you have, at a minimum, read access. The same targeted region can contain multiple sgRNA sequences. These are treated as unique targets and go on individual lines. Each column is explained below.
   2. TargetName
      1. Unique name for the target. Avoid using special characters (`~!@#$%^&(\*}{).
   3. Chr
      1. Chromosome target is on.
   4. Start
      1. 5’ genomic position of PCR amplicon containing cut site.
   5. Stop
      1. 3’ genomic position of PCR amplicon containing cut site.
   6. sgRNA\_Seq
      1. The 5’ → 3’ sequence of the sgRNA. This is not relative to the genomic sequence. The cleavage site will always be at the -3 position from the 3’ end.
   7. ReverseComp
      1. If the sgRNA sequence is not on the forward strand of the genomic DNA then answer “Yes”, otherwise answer “No”.
   8. Comments
      1. Any notes or other words of wisdom about this target.
2. Options File
   1. This is a shell file that must be a formatted as a tab delimited text file. In the docs folder you will find template options file *run\_ScarMapper\_IndelProcessing.sh* for INDEL searching and *run\_ScarMapper\_Combine.sh* for combining output files.
3. Primer Phasing File
   1. This is a tab delimited text file. The file contains the information that allows ScarMapper to quantify which phased primers are contained in each read.
   2. Not required for Ramsden platform.

## Primer Phasing File

These libraries contain no diversity for the first 35 nucleotides or so causing Illumina platforms to crash. To solve this, I use a set of phased primers. Generally, six forward and six reverse primers, each 1 nucleotide longer making the read starts different. These are pooled for the PCR step during library prep. For example, primers we have used for the Lamin Receptor B locus.

|  |  |  |  |
| --- | --- | --- | --- |
| **Primer Name** | **Orientation** | **Location** | **Sequence** |
| LBR2.1 F0 | Forward | chr1:225423928-225423949 | CGACGCTCTTCCGATCTTCAATTCAAGCTCTGTTCCATC |
| LBR2.1 F1 | Forward | chr1:225423927-225423949 | CGACGCTCTTCCGATCTTTCAATTCAAGCTCTGTTCCATC |
| LBR2.1 F2 | Forward | chr1:225423927-225423949 | CGACGCTCTTCCGATCTCTTCAATTCAAGCTCTGTTCCATC |
| LBR2.1 F3 | Forward | chr1:225423927-225423949 | CGACGCTCTTCCGATCTACTTCAATTCAAGCTCTGTTCCATC |
| LBR2.1 F4 | Forward | chr1:225423927-225423949 | CGACGCTCTTCCGATCTGACTTCAATTCAAGCTCTGTTCCATC |
| LBR2.1 F5 | Forward | chr1:225423927-225423949 | CGACGCTCTTCCGATCTAGACTTCAATTCAAGCTCTGTTCCATC |
| LBR2.1 R0 | Rcomp | chr1:225424162-225424143 | CGTGTGCTCTTCCGATCTTCAGCCTGTGGAAAAAGACG |
| LBR2.1 R1 | Rcomp | chr1:225424163-225424143 | CGTGTGCTCTTCCGATCTATCAGCCTGTGGAAAAAGACG |
| LBR2.1 R2 | Rcomp | chr1:225424164-225424143 | CGTGTGCTCTTCCGATCTGATCAGCCTGTGGAAAAAGACG |
| LBR2.1 R3 | Rcomp | chr1:225424165-225424143 | CGTGTGCTCTTCCGATCTTGATCAGCCTGTGGAAAAAGACG |
| LBR2.1 R4 | Rcomp | chr1:225424166-225424143 | CGTGTGCTCTTCCGATCTCTGATCAGCCTGTGGAAAAAGACG |
| LBR2.1 R5 | Rcomp | chr1:225424167-225424143 | CGTGTGCTCTTCCGATCTACTGATCAGCCTGTGGAAAAAGACG |

The sequence that matches the target is TCAATTCAAGCTCTGTTCCATC. The sequence that is not highlighted is for adding the Illumina indices. The phasing sequence is highlighted in green (CT). Phase 0 primers, F0 or R0, contain no extra nucleotides. ScarMapper looks at the first n nucleotides to determine the phasing. Since we use Phase 5 as our maximum for this locus there needs to be 5 nucleotides searched. In the file, any lines that begin with a “#” are treated as comments.

Primer Phase What phase is the primer. Used in the output. For example, R0 is reverse phase 0.

Nucleotides Nucleotides defining the Primer Phase. Must all be the same length.

Read Should ScarMapper search FASTQ1 (R1) or FASTQ2 (R2)?

Locus Locus name for these primers.

## run\_ScarMapper\_IndelProcessing File

This option file is used to process the FASTQ files and find the INDELs. Each parameter is described below.

--IndelProcessing

Options are True or False. This exists to allow the indel search to be turned off in future versions.

--FASTQ1

Full path to FASTQ1

--FASTQ2

Full path to FASTQ2

--RefSeq

Full path to the FASTA genomic reference. The reference index file must be in the same location as the genomic FASTA file

--Master\_Index\_File

Full path to the master index file described above.

-- SampleManifest

Full path to the pooled sample manifest file.

--TargetFile

Full path to the target file.

--WorkingFolder

Full path to a working folder. This is where ScarMapper will write the output files.

--PrimerPhasingFile

Full path to the primer phasing information file.

--Verbose

Set verbosity level. Options are INFO, DEBUG, ERROR. For general runs leave this at INFO.

--Job\_Name

Provide a name for a run. This name will be incorporated into the output files simplifying identification. For this reason avoid special characters such as (`~!@#$%^&(\*}{).

--Spawn

Defines how many parallel jobs to create. Each library defined in the index file will be processes in its own job. Max setting should be number of CPUs – 1. Minimum value is 1.

--Demultiplex

Allowed values are True or False. Defines if demultiplexed FASTQ files are written. If the files are written, they are automatically compressed with gzip with a compression setting of 9.

--HR\_Donor

Sequence used for homologous recombination. If left blank then no HR search is done.

--Platform

Currently Illumina, or Ramsden. This tells ScarMapper how to identify the indices.

--N\_Limit

How many N’s are allowed in each read. Generally, leave this set at 0.01. For Illumina platforms there are seldom any N’s

--Minimum\_Length

Minimum read length. Default is 100 nucleotides.

--OutputRawData

Allowed values are True or False. Determines if additional files are written. These may or may not be useful.

## run\_ScarMapper\_Combine File

--IndelProcessing False

--SampleManifest /full/path/to/SampleManifest\_File.csv

--WorkingFolder This is where the output files will be written

--DataFiles This is the location of the data files to combine. ScarMapper will combine every data file present in the folder matching the name *\*ScarMapper\_Frequency.txt*.

--Verbose INFO

--Job\_Name # Use same Job Name as original Indel Processing run.

--SampleName # This will be part of the output file name

## Indel Processing Output Files

There are three possible output files from the INDEL processing. The main output file containing the scar data will be labeled Job\_Name\_Index\_ScarMapper\_Frequency.txt. Another containing summary data will be labeled Job\_Name\_Index\_ScarMapper\_Summary.txt. The final output is optional and will contain the scar pattern found for each read. The Job\_Name component is from the --Job\_Name parameter described above. The “Index” component is from the first column in the -- SampleManifest. These files will be written in the location defined in the --WorkingFolder parameter. In all cases left and right is relative to the Cas9 cut site based on the sgRNA. If the sgRNA is reverse compliment as defined in the target file, then the sequence listed is the reverse compliment. The column contents are below.

ScarMapper Summary File

* ScarMapper 0.15.0
  + This is the first line in the file. It reports the program version.
* Start: Tue Mar 17 12:18:14 2020
  + This is the date and time the job was started.
* End: Tue Mar 17 12:21:58 2020
  + This is the date and time the job was completed.
* FASTQ1: /mnt/hgfs/Drive\_D/Working/12-March-2020\_R1.fastq.gz
  + This is FASTQ1
* FASTQ2: /mnt/hgfs/Drive\_D/Working/12-March-2020\_R2.fastq.gz
  + This is FASTQ2
* Reads Analyzed: 3591107
  + How many reads were analyzed

# The next are the column headers.

* Index Name
  + From the sample manifest. The “Unidentified” index name is a collection of reads that do not match the sample manifest.
* Sample Name
  + From the sample manifest
* Sample Replicate
  + From the sample manifest.
* Target
  + Target locus from the sample manifest.
* Total Found
  + Number of reads with this index.
* Fraction Total
  + (Total Found) / (Reads Analyzed)
* Passing Read Filters
  + Total Found passing N and length filter
* Fraction Passing Filters
  + (Passing Read Filters) / (Reads Analyzed)

# The phasing columns are only present with “Illumina” platform

* No Read 1 Phasing
  + Read 1 sequences with no identifiable phasing. Usually due to a sequencing error.
* No Read 2 Phasing
  + Read 2 sequences with no identifiable phasing. Usually due to a sequencing error.
* Phase F0
  + Fraction of reads that are forward phase 0.
* Phase F1
  + Fraction of reads that are forward phase 1.
* Phase F2
  + Fraction of reads that are forward phase 2.
* Phase F3
  + Fraction of reads that are forward phase 3.
* Phase F4
  + Fraction of reads that are forward phase 4.
* Phase F5
  + Fraction of reads that are forward phase 5.
* Phase R0
  + Fraction of reads that are reverse phase 0.
* Phase R1
  + Fraction of reads that are reverse phase 1.
* Phase R2
  + Fraction of reads that are reverse phase 2.
* Phase R3
  + Fraction of reads that are reverse phase 3.
* Phase R4
  + Fraction of reads that are reverse phase 4.
* Phase R5
  + Fraction of reads that are reverse phase 5.
* Consensus Fail
  + How many reads were not able to form a consensus?
* No Junction
  + How many consensus sequences did not contain an identifiable junction?
* Scar Count
  + How many consensus sequences contained scars?
* Scar Fraction
  + (Scar Count) / (Scar Count)
* HR Count
  + List, first number is the count of HR products seen once and second value is a count of how many products are seen more than once.
* HR Fraction
  + (sum(HR Count))/( Passing Read Filters)
* Left Deletion Count
  + How many consensus sequences contain a deletion to the left of the cut site with or without insertions or microhomology?
* Right Deletion Count
  + How many consensus sequences contain a deletion to the right of the cut site with or without insertions or microhomology?
* Insertion Count
  + How many consensus sequences contain an insertion with or without deletions?
* Microhomology Count
  + How many consensus sequences contain a microhomology signature with or without insertions?
* Normalized Microhomology
  + (microhomology count) / (scar count)
* TsEJ
  + How many consensus sequences contain a Theta signature End Joining pattern?
* Normalized TsEJ
  + (TsEJ) / (Scar Count)
* NHEJ
  + How many consensus sequences contain a NHEJ signature?
* Normalized NHEJ
  + (NHEJ) / (Scar Count)
* Non-Microhomology Deletions
  + How many consensus sequences contain a deletion without a microhomology signature?
* Normalized Non-MH Del
  + (Non-Microhomology Deletions) / (Scar Count)
* Insertion >=5 +/- Deletions
  + Insertions ≥5 nucleotides with or without deletions.
* Normalized Insertion >=5+/- Deletions
  + (Insertion >=5 +/- Deletions) / (Scar Count)
* Other Scar Type
  + How many consensus sequences contain scars that do not match defined patterns?

ScarMapper Frequency File

This file contains information about the scar pattern seen in each consensus grouped by unique patterns. For this grouping, scar patterns are defined by the string “Left Deletions|Right Deletions|Microhomology|Insertion”.

1. Total
   1. Total number of times the pattern was observed in the sample.
2. Frequency
   1. Total number of times the pattern was observed normalized to the total number of reads in the library that passed filters.
3. Scar Type
   1. TsEJ: Theta signature End Joining
   2. HR: Homologous Recombination
   3. NHEJ: Non-Homologous End Joining
   4. non-MH Deletion: Deletion without microhomology
   5. Insertion: Insertions with or without deletions.
4. Left Deletions
   1. Nucleotides deleted to the left of the cut site.
5. Right Deletions
   1. Nucleotides deleted to the right of the cut site.
6. Deletion Size
   1. The size of the deletion is left + right + size of microhomology.
7. Microhomology
   1. Microhomology sequence.
8. Microhomology Size
   1. Size of microhomology.
9. Insertion
   1. Nucleotides inserted.
10. Insertion Size
    1. Size of insertion.
11. Left Template
    1. Nucleotides, based on insertions, that have homology within 50 nucleotides of the left junction.
12. Right Template
    1. Nucleotides, based on insertions, that have homology within 50 nucleotides of the right junction.
13. Consensus Left Junction
    1. Position of the left junction on the consensus sequence relative to the 5’ end.
14. Consensus Right Junction
    1. Position of the right junction on the consensus sequence relative to the 5’ end.
15. Target Left Junction
    1. Position of the left junction on the genomic target sequence relative to the 5’ end.
16. Target Right Junction
    1. Position of the right junction on the genomic target sequence relative to the 5’ end.
17. Consensus
    1. Consensus sequence.
18. Target
    1. Target region sequence.