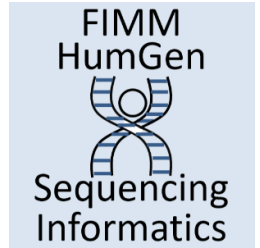


May 10, 2018 Version 1

🌐 Genotype imputation workflow v3.0 V.1

DOI

dx.doi.org/10.17504/protocols.io.nmndc5e



Kalle Pärn¹, Marita A. Isokallio¹, Javier Nunez Fontarnau¹, Aarno Palotie^{2,1}, Samuli Ripatti^{2,1}, Priit Palta^{2,1}

¹FIMM, University of Helsinki; ²equal contribution

FIMM HumGen Sequenci...



Priit Palta

FIMM, University of Helsinki

OPEN  ACCESS



DOI: dx.doi.org/10.17504/protocols.io.nmndc5e

External link: <https://doi.org/10.1038/s41397-022-00270-y>

Protocol Citation: Kalle Pärn, Marita A. Isokallio, Javier Nunez Fontarnau, Aarno Palotie, Samuli Ripatti, Priit Palta 2018. Genotype imputation workflow v3.0. [protocols.io](https://dx.doi.org/10.17504/protocols.io.nmndc5e) <https://dx.doi.org/10.17504/protocols.io.nmndc5e>

Manuscript citation:

Häkkinen K, Kiiski JI, Lähteenvuo M, Jukuri T, Suokas K, Niemi-Pynttäre J, Kiesepä T, Männynsalo T, Wegelius A, Haaki W, Lahdensuo K, Kajanne R, Kaunisto MA, Tuulio-Henriksson A, Kampman O, Hietala J, Veijola J, Lönnqvist J, Isometsä E, Paunio T, Suvisaari J, Kalso E, Niemi M, Tiihonen J, Daly M, Palotie A, Ahola-Olli AV, Implementation of copy-number imputation panel and frequency of key pharmacogenetic variants in Finnish individuals with a psychotic disorder. *The Pharmacogenomics Journal* 22(3). doi: [10.1038/s41397-022-00270-y](https://doi.org/10.1038/s41397-022-00270-y)

License: This is an open access protocol distributed under the terms of the **Creative Commons Attribution License**, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited

Protocol status: Working

We use this protocol and it's working

Created: March 05, 2018

Last Modified: April 01, 2019

Protocol Integer ID: 10638

Keywords: genotype imputation, imputation, Beagle, haplotype phasing, pre-phasing, Eagle

Requirements and preparatory steps

1 The actual imputation protocol begins at step 2.

All consecutive steps (commands given in 'cmd COMMAND' sections) must be run to ensure high-quality results.

For a 'quick and dirty' genotype imputation 'run', you can jump straight to **Steps 10-11** and only run these (assuming you already have all the required files in the correct format).

Throughout the protocol we assume Bash shell.

This **Step 1** defines the requirements for the protocol (e.g. required software packages and reference genome files) and suggests example commands on how to process the files into suitable formats.

In the protocol, we assume human reference genome build version **GRCh38/hg38**. To lift-over and update the build of your chip data, you can use our lift-over protocol: <https://www.protocols.io/view/genotyping-chip-data-reference-genome-build-lift-o-nqtddwn>

Please note that build 38 compatible VCF files should and auxiliary files might have 'chr' prefixes in chromosome names. Therefore, some minor corresponding changes might be required in the related commands to parse/work with these files correctly.

If you prefer GRCh37/hg19 or other genome build versions, please download the corresponding reference genome, map and panel files and modify the suggested commands accordingly.

1.1 Software packages

1.1.1 Download and install the software packages

Required software packages are listed below with the versions used in this protocol. However, using the latest versions is recommended.

- BCFtools v1.7 <http://www.htslib.org/download/>
- R v3.4.1 <https://www.r-project.org/>
- R package data.table <https://github.com/Rdatatable/data.table/wiki/Installation>
- R package sm <https://cran.r-project.org/package=sm>
- Eagle v2.4 <https://data.broadinstitute.org/alkesgroup/Eagle/>
- Beagle v4.1 beagle.27Jan18.7e1.jar <https://faculty.washington.edu/browning/beagle/beagle.html>

1.1.2 Export the paths

Once installed, export the correct paths to environment variable PATH:



```
echo
PATH=/path/to/installed/bcftools/executable/dir:/path/to/installed/Rscript/executable/dir:/path/to/installed/eagle/executable/dir:/path/to/installed/beagle/executable/dir:$PATH >> $HOME/.bashrc source $HOME/.bashrc
```

BCFtools plugin usage requires environment variable BCFTOOLS_PLUGINS exported, e.g:

```
echo export BCFTOOLS_PLUGINS=/path/to/bcftools/plugins >> $HOME/.bashrc source $HOME/.bashrc
```

1.1.3 Install the R packages

Once R is installed, for instance the 'data.table' package can be installed in **R**, e.g.:

```
install.packages('data.table', type = 'source', repos = 'http://Rdatatable.github.io/data.table')
```

Alternatively, if you already downloaded the package:

```
install.packages('/path/to/the/downloaded/data.table_1.10.4.tar.gz', repos = NULL, type = 'source')
```

1.2. Reference genome and genetic map files

1.2.1 Fasta files

Homo Sapiens assembly hg38 version 0 is used and the required files are

- hg38_v0_Homo_sapiens_assembly38.fasta
- hg38_v0_Homo_sapiens_assembly38.fasta.fai

The files are available for downloading at Broad Institute storage in Google cloud at

<https://console.cloud.google.com/storage/browser/broad-references/hg38/v0/?pli=1>

If you prefer GRCh37/hg19, the reference genome files are available for downloading at Ensembl site at

<https://grch37.ensembl.org/index.html>

1.2.2. Genetic map files for phasing with Eagle

Genetic map file (all chromosomes in a single file) with recombination frequencies is downloaded together with Eagle for **GRCh38/hg38**.

- genetic_map_hg38_withX.txt.gz

We have processed the file according to the command below in order to split it per chromosome.

The resulting files are saved as:

- eagle_chr#_b38.txt (where # is the chromosome number)

```
# Take the lines for each chromosome separately, # add a header row and store into
a .txt file for chr in {1..23}; do      zcat genetic_map_hg38_withX.txt.gz | \
grep ^$chr | sed '1chr position COMBINED_rate(cM/Mb) Genetic_Map(cM)' \      >
eagle_chr${chr}_b38.map done
```

Note: Currently the chromosome notation in the Eagle genetic map files is only the chromosome number without 'chr' and chrX is '23'.

Note: Starting from Eagle v2.4, also chromosome notation with 'chr' tag is supported.

If you prefer GRCh37/hg19, the genetic map file is available for downloading at Eagle download page at

<https://data.broadinstitute.org/alkesgroup/Eagle/downloads/tables/>

- genetic_map_hg19_withX.txt.gz

1.2.3 Genetic map files for imputation with Beagle

We have processed the **GRCh38/hg38** Eagle genetic map files (provided by Eagle without 'chr' tag and chrX as '23') to be suitable for Beagle according to the commands below.

First, confirm the format of the downloaded Eagle genetic map files and make required changes such that the chromosome notation is with 'chr' tag and chromosome 23 is 'chrX'.

The resulting files are saved as:

- beagle_chr#_b38.map (where # is the chromosome number)

```
# For each Eagle genetic map file, re-order the columns, remove headers, add 'chr'
and replace chr23 with chrX for chr in {1..23}; do
filename=eagle_chr${chr}_b38.map      paste <(cut -d' ' -f1-2 $filename | sed
'1d' | sed 's/^/chr/;s/chr23/chrX/') \ <(cut -d' ' -f4 $filename | sed '1d') \
<(cut -d' ' -f2 $filename | sed '1d') | \      awk -v OFS='\t' '$2=.' {print}' >
beagle_chr${chr}_b38.map done
```

Note: Chromosome notation in the Beagle genetic map files is 'chr#' and chromosome 23 is 'chrX'.

If you prefer GRCh37/hg19, the genetic map file is available for downloading at Beagle site:

http://bochet.gcc.biostat.washington.edu/beagle/genetic_maps/

- plink.GRCh37.map.zip

1.3. Imputation reference panel files

1.3.1 Obtain the reference panel files

For increased imputation accuracy we recommend using a population-specific imputation reference panel, if available.

If population-specific reference data is not available, for instance 1000 Genomes Project (www.nature.com/articles/nature15393) data can be used instead.

GRCh38/hg38 files are available at EBI 1000 genomes ftp site at

ftp://ftp.1000genomes.ebi.ac.uk/vol1/ftp/release/20130502/supporting/GRCh38_positions/

GRCh37/hg19 files are available at Beagle site already processed to be compatible with Beagle:

http://bochet.gcc.biostat.washington.edu/beagle/1000_Genomes_phase3_v5a/

The 1000 Genomes Project files can be downloaded for instance with command:

```
wget -np
ftp://ftp.1000genomes.ebi.ac.uk/vol1/ftp/release/20130502/supporting/GRCh38_positio
ns/*
```

Save the phased reference panel VCF files per chromosome as follows (for consistency with the commands in the protocol):

- panel_phased_chr#.vcf.gz (where # is chromosome number)

NOTE: The reference panel files should contain non-missing, phased genotypes, chrX as diploid genotypes and all variants as biallelic records!

If your reference panel files are not in correct format, see some suggested commands below.

Also Eagle provides guidelines for processing the GRCh38/hg38 1000 Genomes Project files at:

<https://data.broadinstitute.org/alkesgroup/Eagle/#x1-320005.3.2>

1.3.2 Check for multiallelic sites

Our v3.0 imputation workflow can also impute multiallelic sites, i.e. multiple alternative alleles at the same site, but these multiallelic variants MUST be **decomposed** (be split and represented as a set of biallelic variants) in the reference panel files.



Confirm that in your reference panel files, multiallelic sites (if present) are decomposed. If they are not, use the example command below to split the multiallelic sites into biallelic records:

```
for chr in {1..23}; do    bcftools norm -m -any panel_phased_chr${chr}.vcf.gz -Oz
-o panel_phased_split_multiallelic_chr${chr}.vcf.gz done
```

1.3.3 Check the chromosome notation in GRCh38/hg38 reference panel files

Confirm that the chromosome notation in your reference panel files follows the GRCh38/hg38 notations as 'chr#' for autosomal, 'chrX' for chromosome 23 and 'chrM' for mitochondrial sites. If not, adapt the example command below according to your files and rename the chromosomes:

```
# Create a list of all chromosome names in space-delimited format # Example of
chr_names.txt file: 1 chr1 2 chr2 ... 23 chrX X chrX MT chrM bcftools annotate --
rename-chrs chr_names.txt input.vcf.gz -Oz -o output.vcf.gz
```

1.3.4 Generate a list of the reference panel sample IDs

List of sample IDs present in the reference panel, one line per sample ID, save with filename

- panel_sample_IDs.txt

The list of sample IDs can be generated from any of the VCF files (here chr22) as in the example below (assuming that all chromosomes contain the same set of samples):

```
bcftools query -l panel_phased_chr22.vcf.gz > panel_sample_IDs.txt
```

1.3.5 Reference panel allele frequencies

Generate a tab-delimited file of the reference panel allele frequencies, one variant per line, with columns CHR, SNP (in generated file header replaced with CHR_POS_REF_ALT), REF, ALT, AF (including the header line); note last for loop in following Bash script.

Use the phased reference panel VCF files as input with the example command below and save the file as

- panel.frq



```
# Check your reference panel VCF and if it does NOT contain AF in the INFO field,
calculate it with +fill-tags plugin # Note: it requires environmental variable
BCFTOOLS_PLUGINS exported (Step 1.2) for chr in {1..23}; do bcftools +fill-tags
panel_phased_chr${chr}.vcf.gz -Oz -o panel_phased_chr${chr}_AF.vcf.gz -- -t AF done
# Generate a tab-delimited header for the allele frequency file echo -e
'CHR\tSNP\tREF\tALT\tAF' > panel.frq # Query the required fields from the VCF file
and append to the allele frequency file for chr in {1..23}; do bcftools query -
f '%CHROM\t%CHROM\t%POS\t%REF\t%ALT\t%REF\t%ALT\t%INFO/AF\n'
panel_phased_chr${chr}.vcf.gz >> panel.frq done
```

Note: Chromosome notation in the *panel.frq* file should follow the GRCh38/hg38 notations ('chr#' for autosomal chromosomes and 'chrX' for chromosome 23).

1.3.6 Create binary reference panel files

The phased reference panel files per chromosome are required in bref format (bref = binary reference. For more information see Beagle documentation at Beagle site:

<https://faculty.washington.edu/browning/beagle/bref.16Dec15.pdf>.

The required **bref.*.jar** is downloaded together with Beagle.

Use the phased reference panel VCFs as inputs for the example command below which saves the output files as:

- panel_phased_chr#.bref (where # is chromosome number)

```
# Convert each VCF to bref format for chr in {1..23}; do java -jar
bref.08Jun17.d8b.jar panel_phased_chr${chr}.vcf.gz done
```

1.4. You are ready to start!

As the last preparatory step, let's go over the required input data file(s) and also expected final output files!

1.4.1 Input file:

Post-QC chip genotype data in VCFv4.2 format:

- <dataset>.vcf.gz

Note: Chromosome notation should follow the GRCh38/hg38 notations (e.g. 'chr#' for autosomal chromosomes, 'chrX', 'chrY' and 'chrM').

Note: If the input data was lifted over from an older genome build to version 38, cautious inspection of the data is highly recommended before proceeding with the protocol.



1.4.2 Final output files:

- <dataset>_imputed_info_chr#.vcf.gz (where # is chromosome number)
- <dataset>_postimputation_summary_plots.pdf

Note: Several intermediate files are created during the protocol. Those files can be used for troubleshooting and deleted once the successful imputation is confirmed.

Chip data validation and VCF formatting

- 2 Only autosomal and X chromosomes are kept for the imputation.

Input file:

- <dataset>.vcf.gz

Output file:

- <dataset>_chrfiltered.vcf.gz

Note: Confirm the results for example by comparing the input and output file sizes and line counts.

Command

paste parameter:

-d delimiter

bcftools view parameters:

-t targets

^ exclusion prefix

-Oz compressed output

```
# Generate a comma-separated string of chromosome names to keep
chrs=$(paste -d ' ' <(echo chr{1..22}) <(echo chrX) | tr ' ' ',')
# Keep only those wanted chromosomes
bcftools view -t $chrs <dataset>.vcf.gz -Oz -o <dataset>_chrfiltered.vcf.gz
```

- 3

Align the variant alleles to human reference genome to correct for any dataset-specific REF/ALT flips.

Ensure that only biallelic sites are kept in the chip data, as 'bcftools norm' may introduce false multiallelic sites.

Finally, replace the ID column with a 'SNP ID' in format CHROM_POS_REF_ALT ie. chromosome_position_<reference allele>_<alternative allele>.

**Input files:**

- <dataset>_chrfiltered.vcf.gz
- hg38_v0_Homo_sapiens_assembly38.fasta

Output file:

- <dataset>_SNPID.vcf.gz

Note: Confirm the results for example by comparing the input and output file sizes and line counts.

Command

bcftools norm parameters:

-f reference genome

-c what to do when incorrect/missing REF allele is encountered:

ws warn (w) and set/fix (s) bad sites

bcftools view

-m minimum number of alleles listed in REF and ALT columns

-M maximum number of alleles listed in REF and ALT columns

-Ou uncompressed output

-Oz compressed output

--threads number of threads to use for output compression

bcftools annotate parameter:

--set-id set ID column, % indicates a VCF field

```
# Align the alleles to the reference genome
bcftools norm -f hg38_v0_Homo_sapiens_assembly38.fasta -c ws
<dataset>_chrfiltered.vcf.gz -Ou | \
# Keep only biallelic records
bcftools view -m 2 -M 2 -Oz -o <dataset>_refcorrected.vcf.gz
# Replace the ID column with a CHR_POS_REF_ALT 'SNP ID'
bcftools annotate --set-id '%CHROM\_%POS\_%REF\_%ALT'
<dataset>_refcorrected.vcf.gz -Oz -o <dataset>_SNPID.vcf.gz
```

- 4 Ensure that duplicate individuals do not exist in the chip data or between the chip and reference panel as this would compromise the imputation.

Input files:

- <dataset>_SNPID.vcf.gz
- panel_sample_IDs.txt

**Output file:**

- <dataset>_noduplicate_samples.vcf.gz

Note: Confirm the results for example by comparing the input and output file sizes and line counts.

Command**bcftools query parameters:**

-l list of sample IDs

uniq

-d only print duplicate lines

bcftools view parameters:

-S file of sample IDs to include

^ exclusion prefix

--force-samples only warn about unknown subset of samples

-Oz compressed output

```
# Copy the panel sample ID file with a different name to the working directory
cp /path/to/panel_sample_IDs.txt duplicate_sample_IDs.txt
# Generate a list of sample IDs from the chip data, keep only duplicates and
append to the list of reference panel sample IDs
bcftools query -l <dataset>_SNPID.vcf.gz | uniq -d >> duplicate_sample_IDs.txt
# Remove the listed sample IDs from the chip data VCF
bcftools view -S ^duplicate_sample_IDs.txt --force-samples
<dataset>_SNPID.vcf.gz -Oz -o <dataset>_noduplicate_samples.vcf.gz
```

- 5 Ensure that there are no duplicate variants (these might appear in some chip genotype datasets). If duplicate variants are present, they need to be removed before imputation.

Input file:

- <dataset>_noduplicate_samples.vcf.gz

Output files:

- <dataset>_duplicate_variants.txt
- <dataset>_noduplicate_variants.vcf.gz

Note: Confirm the results for example by comparing the input and output file sizes and line counts.

**Command**

bcftools query parameters:

-f query fields

% identicate the field

uniq parameter:

-d only print duplicate lines

bcftools view parameters:

-e exclusion with expression

expression:

ID=@file IDs included in the file

-Oz compressed output

```
# Store a list of duplicate positions
bcftools query -f '%ID\n' <dataset>_noduplicate_samples.vcf.gz | uniq -d >
<dataset>_duplicate_variants.txt
# Check whether the file contains any variants
if [ -s <dataset>_duplicate_variants.txt ]; then # Then remove the duplicate
variants bcftools view -e ID=@<dataset>_duplicate_variants.txt
<dataset>_noduplicate_samples.vcf.gz -Oz -o
<dataset>_noduplicate_variants.vcf.gz
else # If the file is empty i.e. no duplicate variants are present, only
rename the file to be compatible with the next step mv
<dataset>_noduplicate_samples.vcf.gz <dataset>_noduplicate_variants.vcf.gz
fi
```

- 6 Exclude rare variants (redundant step if they are already removed in quality control steps taken before this protocol), and re-calculate the allele frequency to correctly represent the current samples in the dataset.

Input file:

• <dataset>_noduplicate_variants.vcf.gz

Output file:

• <dataset>_AF.vcf.gz

Note: Confirm the results for example by comparing the input and output file sizes and line counts.

**Command**

bcftools view parameters:

-e exclude based on expression

-Ou uncompressed output

bcftools plugin syntax and parameters:

+fill-tags re-calculates/adds INFO field tags

-Oz compressed output

-- separator for plugin-specific parameters

-t define the tags to be re-calculated/added

Alternatively, if all INFO field tags are wanted (see BCFtools documentation for complete list), remove the tag parameter:

bcftools +fill-tags <dataset>_noduplicate_variants.vcf.gz -Oz -o <dataset>_AF.vcf.gz

```
# Remove low allele count variants if they are not already removed
bcftools view -e 'INFO/AC<3 | (INFO/AN-INFO/AC)<3'
<dataset>_noduplicate_variants.vcf.gz -Ou | \
# Re-calculate allele frequency
bcftools +fill-tags -Oz -o <dataset>_AF.vcf.gz -- -t AF
```

- 7 Generate a frequency file for chip data and reference panel allele frequency comparison.

Input file:

• <dataset>_AF.vcf.gz

Output file:

• <dataset>_chip.frq

**Command**

echo parameter:

-e enable interpretation of backslash escapes

bcftools query parameter and syntax:

-f format, where

%field refers to a column in VCF file

expression '%CHROM\t%ID\t%REF\t%ALT\t%INFO/AF\n' generates for each variant

line tab-delimited format of:

CHR, CHR_POS_REF_ALT, REF, ALT, AF

```
# First generate a tab-delimited header for the allele frequency file
echo -e 'CHR\tSNP\tREF\tALT\tAF' > <dataset>_chip.frq
# Query the required fields from the VCF file and append to the allele
frequency file
bcftools query -f '%CHROM\t%ID\t%REF\t%ALT\t%INFO/AF\n' <dataset>_AF.vcf.gz
>> <dataset>_chip.frq
```

- 8 Compare the chip data and reference panel allele frequencies and generate an exclusion list of those variants where AF values differ more than 10 pp.

Download the R script given in 'FILE' link at the end of this step and save it as 'plot_AF.R'.

Set the script as executable for instance with 'chmod +x plot_AF.R' before running it for the first time.

Run the script as indicated in the example command by giving the two frequency files as input arguments.

Input files:

- <dataset>_chip.frq
- panel.frq

Output files:

- <dataset>_AFs.jpg
- <dataset>_AF_hist.jpg
- <dataset>_exclude.txt

!! Inspect the generated plots before proceeding to the next step:

See in the expected results section at the end of this step, for examples of plots from a high-quality dataset.



- <dataset>_AFs.jpg

Comparison of the chip AF values to the panel AF values. Ideally, it should show a quite tight, uniform diagonal line of increasing slope (from bottom left to top right).

Variants with AF values differing more than 10 pp are marked with red color and included to the exclusion list.

- <dataset>_AF_hist.jpg

Distribution of the AF values. Ideally the histogram should be smooth and skewed toward the smallest AFs.

Command

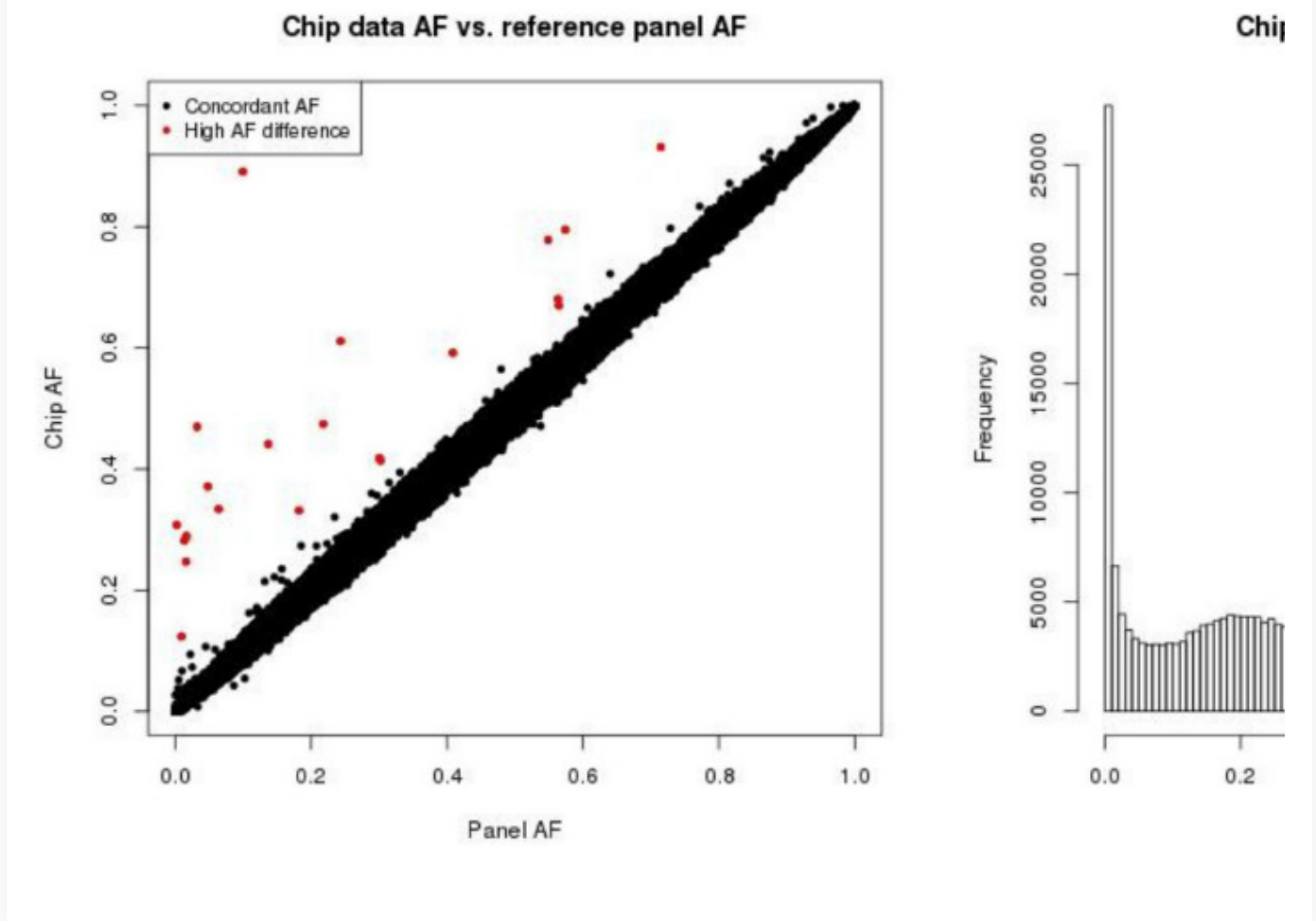
```
# Copy and save the given 'plot_AF.R' file and run it with:  
Rscript --no-save /path/to/plot_AF.R <dataset>_chip.frq /path/to/panel.frq
```

Command

```
#!/bin/env Rscript --no-save  
# Genotype imputation protocol v3 - pre-imputation allele frequency plots  
# Written by Kalle Pärn, Marita A. Isokallio, Paavo Häppölä, Javier Nunez Fontarnau  
and Priit Palta  
# Required packages  
library(data.table) # For fast fread()  
# Input variables  
args <- commandArgs(TRUE)  
indata <- args[1]  
paneldata <- args[2]  
# Read in the frequency files  
chip <- fread(indata, header = T)  
panel <- fread(paneldata, header = T)  
# Generate a dataset tag  
indataset <- sub(
```

Expected result

Examples of <dataset>_AFs.jpg and <dataset>_AF_hist.jpg plots.



 plot_af.r

9 Exclude the variants with highly discordant allele frequencies as listed in the previous step.

Input files:

- <dataset>_exclude.txt (output from step8)
- <dataset>_AF.vcf.gz (output from step 6)

Output files:

- <dataset>_exclude_sorted.txt
- <dataset>_for_phasing.vcf.gz

Note: Confirm the results for example by comparing the input and output file sizes and line counts.

**Command**

bcftools view parameters:

-e exclusion

expression:

ID=@file IDs in indicated file

-Oz compressed output

```
# Sort the exclusion list
sort -V <dataset>_exclude.txt > <dataset>_exclude_sorted.txt
# Exclude the variants
bcftools view -e ID=@<dataset>_exclude_sorted.txt <dataset>_AF.vcf.gz -Oz -o
<dataset>_for_phasing.vcf.gz
```

Chip data pre-phasing

- 10 Chip data pre-phasing will speed up the genotype imputation step.
Phase haplotypes for each chromosome separately before imputation.

Input files:

- <dataset>_for_phasing.vcf.gz
- eagle_chr#_b38.map (where # is chromosome number)

Output file:

- <dataset>_for_imputation_chr#.vcf.gz (where # is chromosome number)

Note: Confirm the results for example by comparing the input and output file sizes and line counts.

Command

```
# Run phasing for each chromosome
for chr in {1..23}; do # Chromosome 23 is coded as 'chrX' in Eagle, whereas
autosomal chromosomes are chromosome numbers alone if [
```

Genotype imputation

11 Run genotype imputation for each chromosome separately.

Input files:

- <dataset>_for_imputation_chr#.vcf.gz
- panel_phased_chr#.bref (where # is chromosome number)
- beagle_chr#_b38.map (where # is chromosome number)

Output file:

- <dataset>_imputed_chr#.vcf.gz (where # is chromosome number)

Command

The command here is split on multiple lines for better readability. However, if the command is copied from here, spaces/tabs may not be correct and cause an error. In case of errors, first try to reformat the command to a single line.

beagle parameters:

gt - a VCF file containing the genotypes

ref - a VCF file containing the phased reference genotypes

map - PLINK format genetic map on the cM scale

out - output file prefix

nthreads - number of threads

niterations - number of phasing iterations

ne - effective population size when imputing ungenotyped markers

impute - whether markers that are present in the reference panel but absent in your data will be imputed

gprobs - whether a GP format field (genotype probability) will be included in the output VCF file when imputing ungenotyped markers

seed - seed for the random number generator

```
# Run imputation for each chromosome
for chr in {1..23}; do java -Xss5m -Xmx16g -jar beagle.jar \ gt=
<dataset>_for_imputation_chr${chr}.vcf.gz \ ref=panel_phased_chr${chr}.bref \
map=beagle_chr${chr}_b38.map \ out=<dataset>_imputed_chr${chr} \ nthreads=16
\ niterations=10 \ ne=20000 \ impute=true \ gprobs=true \ seed=-99999
done
```

Post-imputation processing and quality assurance

12 Post-imputation processing

Re-calculate/add INFO field values and compute Impute2-like INFO scores for each variant.

Input file:

- <dataset>_imputed_chr#.vcf.gz (where # is chromosome number)

Output files:

- <dataset>_imputed_chr#.vcf.gz.tbi (where # is chromosome number)
- <dataset>_imputed_info_chr#.vcf.gz (where # is chromosome number)

Command

bcftools plugins syntax and parameters:

+fill-tags re-calculates/adds INFO field tags (see BCFtools documentation for complete list)

-- separator for plugin-specific parameters

-t define the tags to be re-calculated/added

+impute-info computes Impute2-like INFO score

-Ou uncompressed output

-Oz compressed output

Alternatively, if all INFO field tags are wanted, remove the plugin-specific parameter:

bcftools +fill-tags <dataset>_imputed_chr\${chr}.vcf.gz -Ou

```
# Re-calculate and add INFO field values for each chromosome
for chr in {1..23}; do # Create index file      bcftools index -t
<dataset>_imputed_chr${chr}.vcf.gz # Re-calculate allele frequency and
compute Impute2-like INFO score bcftools +fill-tags
<dataset>_imputed_chr${chr}.vcf.gz -Ou -- -t AF | \ bcftools +impute-info -Oz
-o <dataset>_imputed_info_chr${chr}.vcf.gz
done
```

13 Imputation QA

Extract allele frequencies (AF) and INFO scores from the imputed VCF file.

Group the variants by their AF into either of the following categories,

- 1: AF >= 5% or AF <= 95% (common variants)
- 2: 0.5% <= AF < 5% or 95% < AF <= 99.5% (low-frequency variants)
- 3: AF < 0.5% or AF > 99.5% (rare variants)

Input file:

- <dataset>_imputed_info_chr#.vcf.gz (where # is chromosome number)

Output file:

- <dataset>_chr#_varID_AF_INFO_GROUP.txt (where # is chromosome number)

Command

```
# Generate an allele frequency file for plotting for each chromosome
for chr in {1..23}; do # Generate a header for the output file echo -e
'CHR\tSNP\tREF\tALT\tAF\tINFO\tAF_GROUP' >
<dataset>_chr${chr}_varID_AF_INFO_GROUP.txt # Query only the required
fields and add allele frequency group (1, 2 or 3) as the last column
bcftools query -f
'%CHROM\t%CHROM\t%POS\t%REF\t%ALT\t%REF\t%ALT\t%INFO/AF\t%INFO/INFO\t-\n'
<dataset>_imputed_info_chr${chr}.vcf.gz | \ # $5 refers to AF values, $7
refers to AF group awk -v OFS=
```

14 Imputation QA

Produce multiple plots to illustrate the distribution of Impute2-like INFO scores and allele frequencies of the imputed data, as well as the comparison of allele frequencies between the imputed data and the reference panel.

Download the R script given in 'FILE' link at the end of this step and save it as 'plot_INFO_and_AF_for_imputed_chrs.R'. Set the script as executable for instance with 'chmod +x plot_INFO_and_AF_for_imputed_chrs.R' before running it for the first time.

Run the script as indicated in the example command by giving the dataset name and panel frequency files as input arguments.

Input files:

- panel.frq
- <dataset>_chr#_varID_AF_INFO_GROUP.txt (where # is chromosome number)

Output files:

- <dataset>_chr#_postimputation_summary_plots.png (where # is chromosome number)
- <dataset>_postimputation_summary_plots.pdf

!! NOTE: If the number of variants in your dataset is very small, modify the 'plot_INFO_and_AF_for_imputed_chrs.R' script on line 30-31 to contain all variants.

**!! Inspect the plots:**

See example of the produced plots in expected results section at the end of this step.

Top left:

Impute2-like INFO score density for each AF group.

Bottom left:

AF distribution of the imputed chip data.

Top right:

AF comparison between the panel and imputed chip data.

Bottom right:

Absolute AF difference along the chromosome positions between the panel and imputed chip data.

Command

```
# Copy and save the given 'plot_INFO_and_AF_for_imputed_chrs.R' file and run it with:
Rscript --no-save /path/to/plot_INFO_and_AF_for_imputed_chrs.R <dataset>
/path/to/panel.frq
# Combine the plots per chromosome into a single pdf file
convert $(ls <dataset>*postimputation_summary_plots.png | sort -V)
<dataset>_postimputation_summary_plots.pdf
```

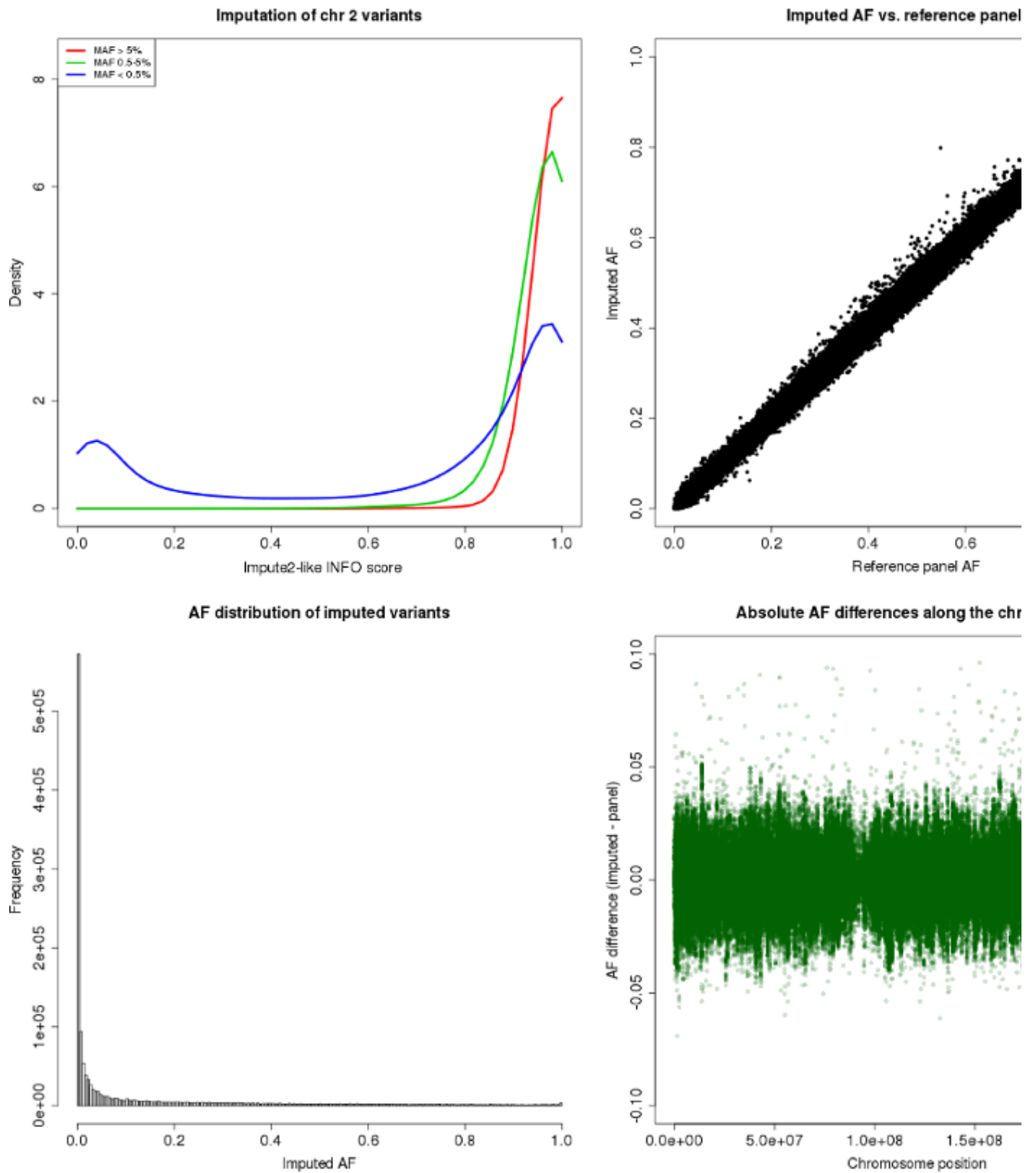



Command

```
#!/bin/env Rscript --no-save
# Genotype imputation protocol v3 - post-imputation QA plots
# Written by Kalle Pärn, Marita A. Isokallio, Paavo Häppölä, Javier Nunez Fontarnau
and Priit Palta
# Required packages
library(data.table) # for fast fread()
library(sm) # for density plotting
# Input variables
args <- commandArgs(TRUE)
indataset <- args[1]
paneldata <- args[2]
# Reference panel frequency file
panel <- fread(paneldata, header = T)
# Generate plots and save as a png file per chromosome
for (chr in 1:23) { print(paste(
```

Expected result

Example of chromosome 2 post-imputation summary plots.



 plot_info_and_af_for_imputed_chrs.r