

IGREX for quantifying the impact of genetically regulated expression on phenotypes

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Introduction

This vignette provides an introduction to the `iGREX` package. R package `iGREX` implements iGREX, a statistical model for quantifying the impact of genetically regulated expression on complex traits and diseases. The package can be installed with the command:

```
library(devtools)
```

```
install_github("mxcai/iGREX")
```

The package can be loaded with the command:

```
library("iGREX")
```

Fit iGREX using simulated data

We first demonstrate the workflow of iGREX using simulated data. The genotype matrix can be simulated using `genRawGeno` function:

```
library(mvtnorm)
set.seed(10)
n1 <- 1000
n2 <- 4000
p <- 100 #number of SNPs in each gene
G <- 200 #number of genes
maf <- runif(p*G, 0.05, 0.5)
rho <- 0.8
X <- genRawGeno(maf,p,G,rho,n1+n2)
X1 <- X[1:n1,]
X2 <- X[(n1+1):(n1+n2),]
```

Then, cis effect sizes are generated from standard Gaussian distribution with sparse structure. We set only 20% of cis effects as non-zero, and control the cellular level heritability at $h_y^2 = 0.3$.

```
sb2_true <- 0.3
sy2_true <- 0.7
Y0 <- matrix(0,n1+n2,G)
for(g in 1:G){
  nonzero <- rbinom(p,1,0.2)
  if(sum(nonzero)==0) nonzero[1] <- 1
  beta <- rnorm(p,0,sqrt(sb2_true/sum(nonzero)))
  beta[nonzero==0] <- 0
  Y0[,g] <- X[,((g-1)*p+1):(g*p)] %*% beta
}
Y <- Y0[1:n1,] + matrix(rnorm(n1*G,0,sqrt(sy2_true)),n1,G)
```

Finally, the phenotype data is generated as the generative model of iGREX with variance components specified as $h_{GREX}^2 = 0.2$, $h_{Alternative}^2 = 0.3$. GREX effects are also sparse with only 20% non-zero:

```
sg2_true <- 0.2
sa2_true <- 0.3
t <- mean(diag(Y0[(n1+1):(n1+n2)],)%*%t(Y0[(n1+1):(n1+n2)],)))
nonzero <- rbinom(G,1,0.2)
if(sum(nonzero)==0) nonzero[1] <- 1
alpha <- as.matrix(rnorm(G,0,sqrt(sg2_true/t*G/sum(nonzero))))
alpha[nonzero==0] <- 0
z0 <- Y0[(n1+1):(n1+n2),] %*% alpha
gamma <- as.matrix(rnorm(p*G,0,sqrt(sa2_true/(p*G))))
z1 <- X2%*%gamma
z <- z0 + z1 + rnorm(n2,0,sqrt(var(z0+z1)))
```

Stage one iGREX solves G linear mixed models using PX-EM algorithm and calculate K_{GREX} and $K_{Alternative}$.

```
X <- scale(X)
X1 <- X[1:n1,]
X2 <- X[(n1+1):(n1+n2),]
K <- K0 <- 0
for(g in 1: G){
  y_g <- Y[,g]
  X1tmp <- X1[,((g-1)*p+1):(g*p)]
  X2tmp <- X2[,((g-1)*p+1):(g*p)]
  W1 <- matrix(1,n1,1)
  fit_g <- iGREX_Kg(y_g,X1tmp,X2tmp,W1,1e-5,500)
  K <- K + fit_g$K_g
  K0 <- K0 + fit_g$K_g0
}
Ka <- X2 %*% t(X2) / ncol(X2)
K <- K/mean(diag(K))
K0 <- K0/mean(diag(K0))
```

Stage two iGREX fit variance components model using either REML or MoM:

```
# REML
REML <- REML_3var(K,Ka,z,verbose=F)

# REML without accounting for uncertainty
REML0 <- REML_3var(K0,Ka,z,verbose=F)

# exact estimate by MoM
MoM <- MoM_3var(K,Ka,z)

# exact estimate by MoM without accounting for uncertainty
MoM0 <- MoM_3var(K0,Ka,z)
```

The \widehat{PVE}_{iGREX} and $\widehat{PVE}_{Alternative}$ as well as their standard errors are returned:

```
REML$PVE
```

```
##                PVEg          PVEa          h2          prop
## heritability 0.19961210 0.32283774 0.5224498 0.38206940
## se           0.02425845 0.03231094 0.0317747 0.04382101
```

REMLO\$PVE

```
##                PVEg      PVEa      h2      prop
## heritability 0.13821420 0.36019040 0.49840460 0.27731325
## se          0.01693687 0.03101308 0.03111347 0.03357496
```

MoM\$PVE

```
##                PVEg      PVEa      h2      prop
## heritability 0.22623415 0.32247177 0.54870592 0.41230492
## se          0.04102882 0.05682887 0.05158465 0.07461166
```

MoMO\$PVE

```
##                PVEg      PVEa      h2      prop
## heritability 0.15678177 0.35868778 0.51546955 0.30415331
## se          0.02843961 0.05410814 0.05052657 0.05861697
```

Fit iGREX using individual level genotype and eQTL data

We provide an example of fitting iGREX using GWAS and eQTL data in plink binary format. To use the function, we first specify the input file names:

```
file_qtlgeno <- "GTEx_qc_hm3"
file_GWASgeno <- "NFBC_filter_mph10"
file_expression <- "Liver_gene_expression.txt"
file_qtltcov <- "Liver_cov.txt"
file_GWAScov <- "NFBC_hm3_filter.eigenvec"
load("K_NFBC_hm3.RData")
```

Here, `file_qtlgeno` is the prefix for eQTL genotype data in plink binary format, `file_GWASgeno` is the GWAS data in plink binary format, `file_expression` is the gene expression file with extended name, `file_qtltcov` and `file_GWAScov` are covariates file for eQTL and GWAS data, respectively. For gene expression file, it must have the following format (rows for genes and columns for individuals and note that it must be tab delimited):

| lower | up | genotype1 | genotype2 | TargetID | Chr | HG00105 | HG00115 |
|-----------|-----------|----------------|--------------|--------------------|-----|-----------|------------|
| 59783540 | 59843484 | lincRNA | PART1 | ENSG00000152931.6 | 5 | 0.5126086 | 0.7089508 |
| 48128225 | 48148330 | protein_coding | UPP1 | ENSG00000183696.9 | 7 | 1.4118007 | -0.0135644 |
| 57846106 | 57853063 | protein_coding | INHBE | ENSG00000139269.2 | 12 | 0.5755268 | -1.0162217 |
| 116054583 | 116164515 | protein_coding | AFAP1L2 | ENSG00000169129.8 | 10 | 1.1117776 | 0.0407033 |
| 22157909 | 22396763 | protein_coding | RAPGEF5 | ENSG00000136237.12 | 7 | 0.2831573 | -0.1772559 |
| 11700964 | 11743303 | lincRNA | RP11-434C1.1 | ENSG00000247157.2 | 12 | 0.2550282 | -0.2831573 |

The covariate files must have the following format (rows for individuals and the first two columns are FID and IID):

| V1 | V2 | V3 | V4 | V5 | V6 | V7 | V8 |
|------------|------------|---------|---------|---------|------------|------------|------------|
| GTEx-11DXY | GTEx-11DXY | 0.0109 | -0.0027 | -0.0789 | -0.0552724 | 0.0469389 | 0.0488902 |
| GTEx-11DXZ | GTEx-11DXZ | -0.1053 | -0.0126 | 0.0027 | -0.0097383 | 0.0542790 | -0.0918273 |
| GTEx-11EQ9 | GTEx-11EQ9 | 0.0148 | -0.0078 | -0.0057 | 0.0362291 | 0.0474735 | -0.0502703 |
| GTEx-11GSP | GTEx-11GSP | 0.0168 | -0.0052 | -0.0019 | -0.0505170 | -0.0960899 | -0.0554980 |
| GTEx-11NUK | GTEx-11NUK | 0.0154 | -0.0025 | 0.0049 | -0.0733902 | 0.0009193 | 0.0227932 |
| GTEx-11NV4 | GTEx-11NV4 | -0.1152 | -0.0170 | -0.0223 | -0.0619178 | 0.0035294 | 0.0361403 |

The alternative genetic correlation matrix (Ka) is just the kinship matrix and should be manually computed (which can be done by plink or GEMMA) and supplied to the function. Finally, the analysis can be done by iGREX function:

```
fit <- iGREX(file_qtlgeno,file_GWASgeno,file_expression,file_qtlcov,file_GWAScov,Ka=K,
             whCol=6,bw=500000,subsample = 0,method="MoM")
```

The estimated PVEs are stored in the outcome list and can be accessed by (fit\$output\$PVE)

| | h_R | h_D | h_all | h_med |
|--------------|-----------|-----------|-----------|-----------|
| heritability | 0.1917895 | 0.4069149 | 0.5987045 | 0.3203409 |
| se | 0.0408129 | 0.1001861 | 0.0937858 | 0.0823769 |

Fit iGREX-s using GWAS summary statistics and eQTL data

Next, we provide an example of fitting iGREX-s using GWAS summary statistics and eQTL data with an LD reference. To use the function, we first specify the input file names:

```
file_qtlgeno = file_GWASgeno = "IGREX_data/all_chr_1000G"
file_expression = "IGREX_data/Geuvaradis_gene_expression_qn.txt"
file_qtlcov = file_GWAScov = "IGREX_data/TGP_ref_pc20.eigenvec"
file_z = "IGREX_data/NFBC_HDL_cov20_summary.txt"
load("IGREX_data/K_TGP_height.RData")
```

In this function, file_qtlgeno, file_GWASgeno, file_expression, file_qtlcov and file_GWAScov are of the same format as the ones in iGREX, while an additional GWAS summary statistics file file_z is needed. All the data here are open access: the expression data is from the Geuavadis project, whose samples are from 1000 Genomes Europe ancestry; we use the genotypes of these 1000 Genomes samples as the LD reference panel. All files used here can be downloaded from this [Dropbox link](#). The summary statistics should be of the following format:

| SNP | N | Z | INC_ALLELE | DEC_ALLELE |
|------------|------|------------|------------|------------|
| cnv3p502 | 5123 | -1.3533719 | A | G |
| rs3115860 | 5123 | 0.5287950 | C | A |
| rs3131967 | 5123 | 0.7043162 | A | G |
| rs12124819 | 5123 | -0.3059190 | G | A |
| rs17160939 | 5123 | 1.2516159 | G | A |
| rs4475691 | 5123 | 1.1862824 | A | G |

The iGREX-s can then be fitted using iGREXs function:

```
fit_s <- iGREXs(file_qtlgeno,file_GWASgeno,file_expression,file_z,file_qtlcov,file_GWAScov,
                Ka=K,bw = 500000)
```

The estimated PVEs are stored in the outcome list and can be accessed by (fit_s\$output\$PVE)

| | h_R | h_D | h_med |
|--------------|-----------|-----------|-----------|
| heritability | 0.0727114 | 0.4729560 | 0.1332522 |
| se | 0.0435076 | 0.1177819 | 0.0764512 |