Final Project

PUBH 8878, Statistical Genetics

## Purpose

* Analyze real genetic data using methods from the course. Choose one of the tracks below (or propose your own) and produce a succinct, reproducible analysis using a public dataset.
* This project emphasizes scientific reasoning, correct statistical practice, clear communication, and reproducible code. It is intentionally open‑ended: depth > breadth.

## Deliverables

* Project proposal (approx. 1 page): question(s), dataset(s), methods, risks/mitigations, expected outputs. **Due: Wednesday, October 15th by 11:59pm.**
  + Ensure that you are able to access/download your proposed dataset(s)
* Final report (8–12 pages, PDF only): format details below. **Due: Wednesday, November 12th by 11:59pm.**
  + Reproducible materials: a self‑contained folder or repo with your .qmd/R scripts, environment notes, and seeds. Include a README with run instructions.
* 8–10 minute in‑class presentation of key results on **Wednesday, November 12th**

## Format

We will follow the format of the journal [Genetics](https://academic.oup.com/genetics). An Overleaf template can be found [here](https://www.overleaf.com/latex/templates/template-for-preparing-your-submission-to-genetics-using-overleaf/stmpddtqcxtx). The paper should adhere to the following:

* Begin the paper with an original title, followed by your name, the course, and the date
* The paper should have the following sections:
  + Introduction: state the general problem or issue you are addressing.
  + Materials and Methods: describe the methods used to obtain data, analyze data, and to test hypotheses associated with the data.
  + Results: describe the results of the data analysis and hypothesis testing.
  + Discussion: here you draw conclusions about the problem you studied; this section should include a synthesis of ideas.
  + References: List the relevant literature you have read and used to support your arguments/analyze your data. The literature cited should be in the format of the journal Genetics.

## Evaluation (20% of course grade)

* Clarity and scope (20%): well‑posed question, appropriate scope for time/resources.
* Methods and correctness (35%): sound statistical modeling, assumptions stated, correct inference, sensible QC.
* Interpretation and communication (25%): figures/tables support claims, limitations, ethical awareness.
* Reproducibility (20%): organized code, seeds, instructions, figures regenerate.

## Example Topics

* Primary GWAS analysis (individual-level data): perform QC, PCA, GWAS, and post-GWAS analyses. Data is typically available for non-human model organisms.
* Secondary GWAS analysis (summary statistics): pick one trait and perform quality checks, Manhattan plot, locus zoom(s), gene/annotation enrichment, and short literature triangulation, SNP‑heritability via LD Score Regression, cross‑trait genetic correlation.
* Population structure and diversity: PCA/UMAP on a reference genotype panel, compute between populations, visualize allele frequency spectra, explore LD decay, ADMIXTURE/LEA ancestry components.
* Causal inference with two‑sample Mendelian randomization: select a well‑powered exposure/outcome with strong instruments, run multiple MR estimators, perform sensitivity and heterogeneity checks, discuss assumptions and violations.
* Fine‑mapping or colocalization: focus on 1–2 loci, use LD from a reference panel, apply SuSiE/FINEMAP, test GWAS–eQTL colocalization for a tissue of interest.
* Simulation with real LD: simulate phenotypes on a real genotype panel (e.g., chromosome 22) to study power, inflation, or PRS performance under different architectures.

## Ethics & Responsible Use

* Use population labels with care
* Avoid essentialist interpretations
* Discuss portability and fairness when comparing groups
* Do not attempt re‑identification
* Respect each dataset’s license/terms.

## Data Sources (curated)

* [GWAS Catalog (NHGRI–EBI)](https://www.ebi.ac.uk/gwas/): comprehensive registry of GWAS with summary statistics where available; good for trait curation and downloading per‑study results.
* [OpenGWAS (MRC IEU)](https://gwas.mrcieu.ac.uk/): programmatic access to >40k GWAS summary-stat datasets; integrates well with R packages ieugwasr and TwoSampleMR.
* [Pan-UK Biobank (Broad)](https://pan.ukbb.broadinstitute.org/): pan‑ancestry GWAS results across thousands of phenotypes with interactive PheWeb and bulk download.
* [FinnGen](https://www.finngen.fi/en/access_results): large disease‑focused GWAS summary stats and phenotype documentation.
* [Biobank Japan](https://pheweb.jp/): GWAS results across many traits; multi‑ancestry comparison opportunities.
* [GIANT Consortium](https://portals.broadinstitute.org/collaboration/giant/index.php/GIANT_consortium): anthropometric trait GWAS (e.g., height, BMI) — classic, clean testbeds.
* [Psychiatric Genomics Consortium (PGC)](https://www.med.unc.edu/pgc/download-results/): summary stats for psychiatric disorders; read and follow data use terms.
* [1000 Genomes Project (IGSR)](https://www.internationalgenome.org/data): open, phased whole‑genome reference panel with population labels; ideal for PCA, F\_ST, LD, and as an LD reference.
* [HGDP + 1000G combined callset (gnomAD)](https://gnomad.broadinstitute.org/downloads#v3-hgdp-1kg): harmonized WGS panel for global structure analyses (VCF/PLINK).
* [gnomAD v4](https://gnomad.broadinstitute.org/downloads): aggregated exome/genome allele frequencies; excellent for frequency‑based analyses and QC (not individual‑level genotypes).
* [GTEx/eQTL resources](https://www.ebi.ac.uk/eqtl/) and [GTEx v8 summary statistics](https://gtexportal.org/home/datasets) for colocalization.
* [LD reference (for LDSC/fine‑mapping)](https://data.broadinstitute.org/alkesgroup/LDSCORE/) and [baseline annotations](https://github.com/bulik/ldsc): precomputed 1000G LD scores.

### Model‑organism data sources (genotypes + phenotypes where noted)

* (Mouse) [Mouse Phenome Database (MPD)](https://phenome.jax.org/): strain, Collaborative Cross (CC), and Diversity Outbred (DO) resources with extensive phenotypes. Måany datasets include genotypes or QTL‑ready files. Good for GWAS/QTL and replication.
* (Mouse) [International Mouse Phenotyping Consortium (IMPC)](https://www.mousephenotype.org/): high‑throughput knockout phenotypes with rich metadata. Best for functional interpretation.
* (Mouse) [MGI (Mouse Genome Informatics)](https://www.informatics.jax.org/): curated QTL/phenotype annotations and cross references.
* (Mouse/Rat) [GeneNetwork](https://www.genenetwork.org/): genotypes and thousands of phenotypes for reference panels (e.g., BXD, LXS, HXB/BXH). Interactive QTL mapping and downloads.
* (Rat) [Rat Genome Database (RGD)](https://rgd.mcw.edu/) and [PhenoMiner](https://rgd.mcw.edu/phenominer/): strain genotypes/variants with curated phenotypes, supports QTL/GWAS in rat panels.
* (Drosophila) [Drosophila Genetic Reference Panel (DGRP)](https://dgrpool.org/): fully inbred lines with whole‑genome genotypes and many published phenotypes, designed for GWAS across lines.
* (Drosophila) [FlyBase](https://flybase.org/): genome and phenotype annotations, links to population panels and datasets.
* (C. elegans) [CeNDR](https://www.elegansvariation.org/): natural isolates with genotypes and trait data, built‑in GWAS and download portal.
* (C. elegans) [WormBase](https://wormbase.org/): phenotype and functional annotations, pairs well with CeNDR for interpretation.
* (Arabidopsis) [AraGWAS Catalog](https://aragwas.1001genomes.org/) and [AraPheno](https://arapheno.1001genomes.org/): GWAS results, phenotypes, and links to [1001 Genomes](https://1001genomes.org/) genotypes, GWAS‑ready.

## Helpful Resources by Topic

Here are some resources for topics that we will not cover in depth in this course, if you choose to explore them for this project.

### Causal inference (Mendelian randomization)

* [TwoSampleMR documentation](https://mrcieu.github.io/TwoSampleMR/) and [ieugwasr](https://mrcieu.github.io/ieugwasr/): end‑to‑end two‑sample MR from OpenGWAS, with instrument selection, Steiger filtering, heterogeneity, and sensitivity analyses.
* [MendelianRandomization (CRAN)](https://cran.r-project.org/package=MendelianRandomization): MR‑Egger, IVW, weighted median/mode, useful for triangulation.
* [MR‑PRESSO (CRAN)](https://cran.r-project.org/package=MRPRESSO): outlier detection/correction to assess horizontal pleiotropy.
* [CAUSE](https://jean997.github.io/cause/): robust MR under correlated pleiotropy, helpful when standard assumptions are doubtful.

### Fine‑mapping and colocalization

* [susieR](https://stephenslab.github.io/susieR/): Bayesian variable selection and credible sets for fine‑mapping; works with in‑sample or reference LD.
* [FINEMAP](http://www.finemap.me/): summary‑stat fine‑mapping with shotgun stochastic search, supports multiple causal variants per locus.
* [coloc](https://cran.r-project.org/package=coloc): Bayesian colocalization testing for two traits (e.g., GWAS–eQTL), simple priors, clear summaries.
* [eCAVIAR](https://github.com/fhormoz/caviar): probabilistic colocalization allowing multiple causal variants, requires LD and summary stats.

### Simulation with real LD

* [GCTA — simulate phenotypes](http://cnsgenomics.com/software/gcta/): --simu-qt/--simu-cc generate traits on top of real genotype panels (e.g., chr22 PLINK files) using specified architectures.
* [bigsnpr](https://privefl.github.io/bigsnpr/articles/LDpred2.html): R tooling for large genotype matrices. Simulate phenotypes with real LD and evaluate polygenic methods efficiently.
* [HAPGEN2](https://mathgen.stats.ox.ac.uk/genetics_software/hapgen/hapgen2.html): simulate new genotypes from reference haplotypes (1000G/UKBB) to preserve realistic LD patterns.
* [msprime/stdpopsim](https://tskit.dev/msprime/docs/stable/) and [stdpopsim](https://stdpopsim.readthedocs.io/): coalescent simulations with recombination and demographic models, combine with empirical LD panels for hybrid designs.