

Introduction to Statistical Genetics

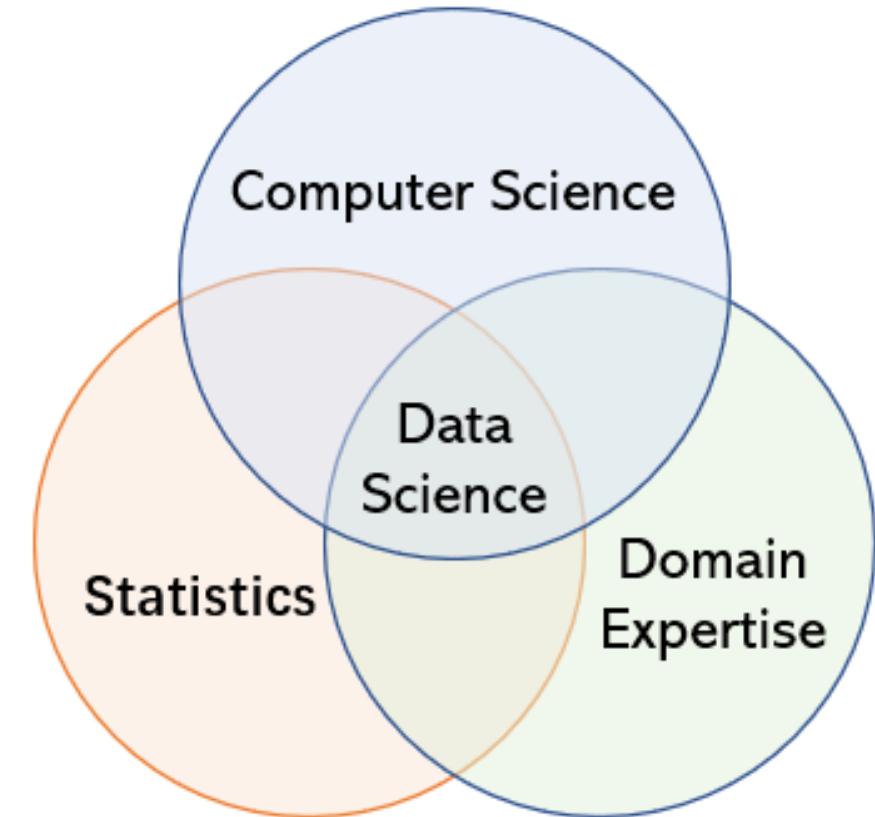
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Introduction

→ What is Statistical Genetics and Genomics?

Big Data: $n > 10^3$, $p > 10^6$ (high-level processed data in GB and raw data in TB)

Complex: (e.g. multiple causal factors, interactions, pathway/network...)



Learning Objectives

- This course provides an INTRODUCTION to concepts and fundamentals in statistical genetics.
- At the end of the course, I hope you will:
 - Understand foundational principles of population genetics.
 - Learn statistical methods commonly used in genetic data analysis.
 - Understand and apply computational and statistical methods used in the design and analysis of genome-wide studies (GWAS).

Course Content

- Background in molecular genetics and basic genetic models
- Concepts from population genetics
- Principles of inheritance
- Aggregation, heritability and segregation analysis
- Genome-wide association studies (GWAS)
 - Quality control
 - Genotype imputation
 - Multiple testing
 - Meta-analyses
 - Population stratification adjustment

Background Needed

- Pre-reqs: [Unix Shell module](#) and [R module](#).
- Assume no formal training in genetics.
 - Basic concepts in molecular genetics will be introduced in the class.
- Familiarity with key concepts in statistical inference, including:
 - Elementary probability and statistical methods
 - Distributions of basic random variables (e.g., binomial, normal)
 - Likelihood-based methods: estimation and hypothesis testing
 - Basic regression techniques (e.g., linear, logistic)

GitHub Repo

https://github.com/UofT-DSI/stat_gen

- Schedule
- These slides (HTML & PDF)
- Our database for live coding
- All in-class code
- Assignment details and rubrics
- Policies, due dates, etc

Useful Online Resources

- **Textbook:** *The Fundamentals of Modern Statistical Genetics* (Nan Laird & Christoph Lange).
- **Introductory Genomics Videos:** [BigBio YouTube Channel – Genomics Playlists](#)
- **Biomedical Data Resource Guide:** [StatsUpAI – Curated Biomedical Datasets](#)

Assignments

- Three assignments (TBA), released on Monday of each week.
- Broken into three sections:
 - Section 1 focuses on review of molecular genetics and basic genetic models
 - Section 2 focuses on population genetics & consequences on genetic association studies
 - Section 3 focuses on Genome-wide association studies
- Review questions/answers in Office Hours course support

Grading

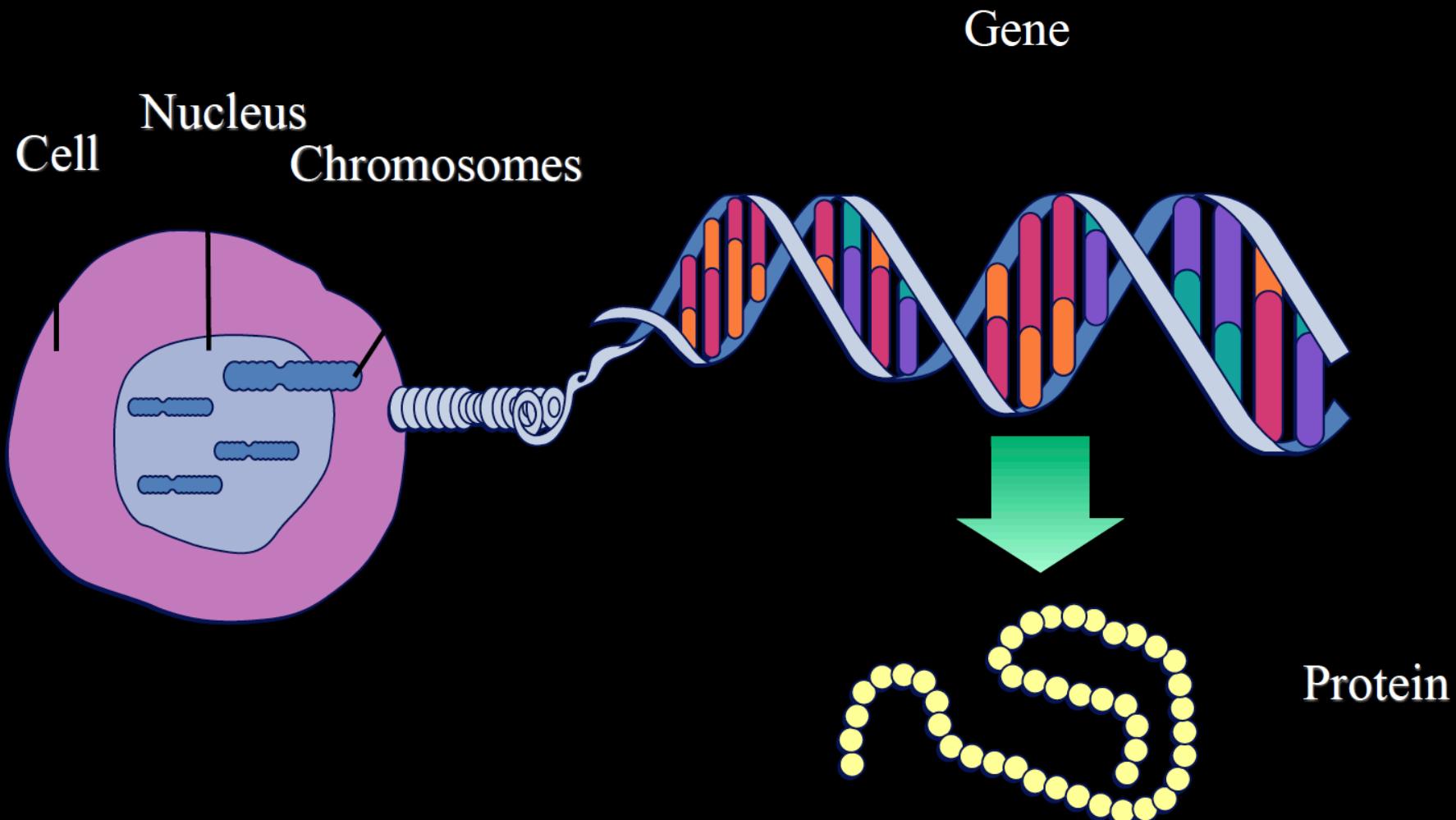
- Pass/Fail. Do the work, pass the course :)
- Assignment 1: TBA
- Assignment 2: TBA
- Assignment 3: TBA
- Review rubrics for full details
- Class Attendance: *not graded this cohort, come anyways!*
 - Let myself or course support know if you are unable to attend a lesson

What questions do you have about the course?

What is Statistical Genetics?

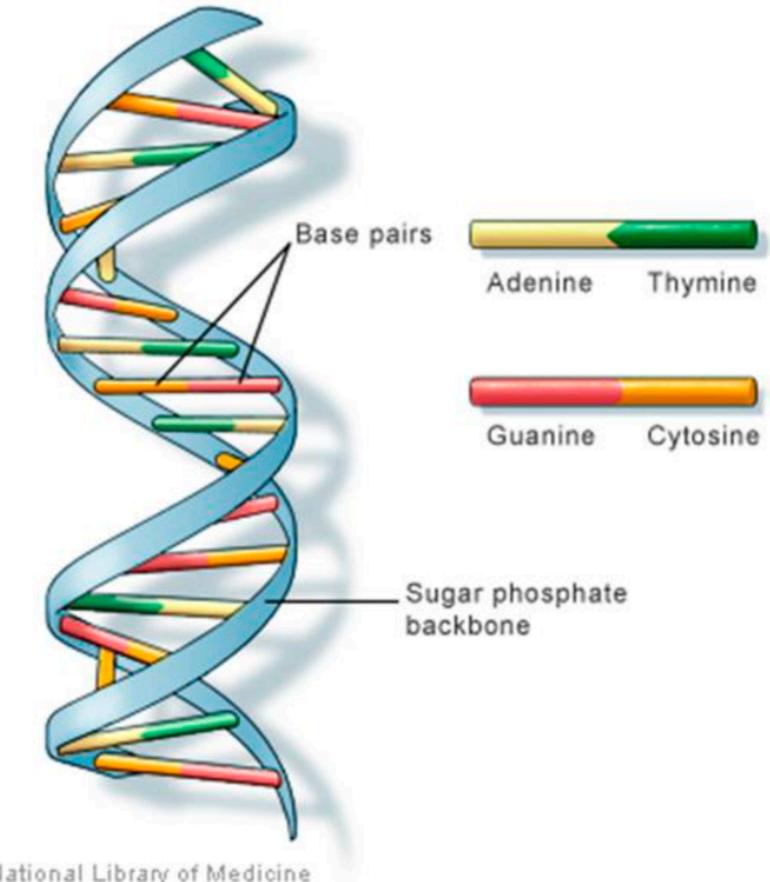
- Statistical genetics is an interdisciplinary field at the interface between statistics and genetics and is concerned with the development of statistical methods for problems in genetics.
- Genetics is a subfield of biology concerned with the study of heredity (transmission of genetic material from parents to offspring) and genetic variation.

Chromosomes, DNA and Genes

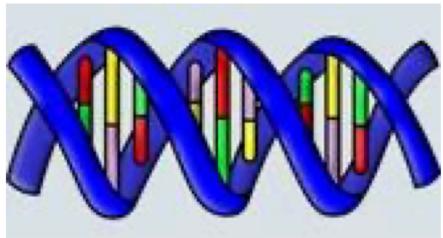


DeoxyriboNucleic Acid (DNA)

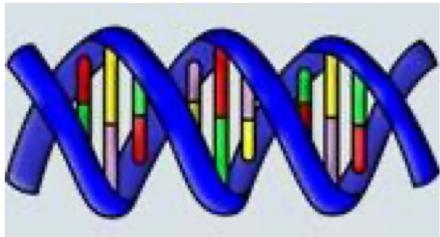
- DNA is the basic biological material of inheritance; it determines how proteins are manufactured in the body
- Each strand of DNA is a long molecule made up of a linear sequence of subunits/base pairs: ATGC.
- A-T and G-C matching: information on one strand is sufficient.
- 'Size' of the genome: \approx 3 billions of DNA base pairs



DeoxyriboNucleic Acid (DNA)



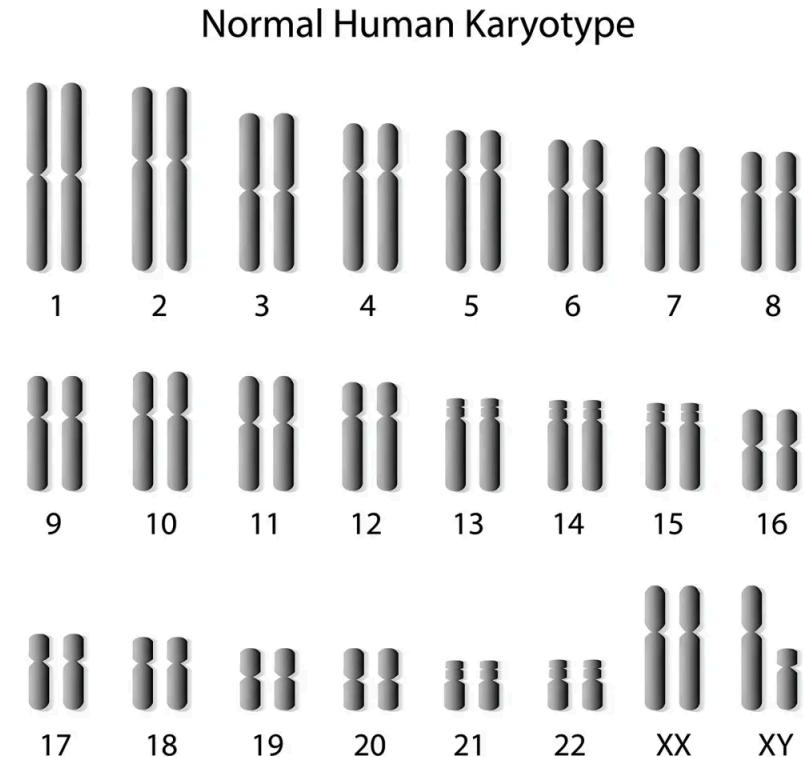
CTCGTCACCTTCAC
GAGGCACTG?????



CTCGTCACCTTCAC

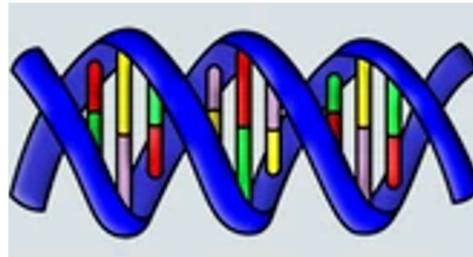
Chromosomes

- Each chromosome has a double helix structure: two long strands of DNA, bounded to each other lengthwise.
- 23 pairs of chromosomes: 22 homologous pairs (Autosomes) and 1 pair of sex chromosomes (XX female, XY male).
- In each pair, one copy is inherited from the mother and one from the father.
- Where genetic material is stored and in the nucleus of every cell.

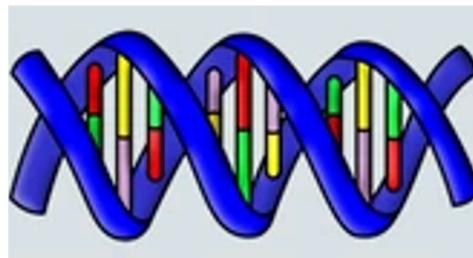


Double Helix Structure

- Each chromosome has two long strands of DNA.
- Homologous chromosome pair:



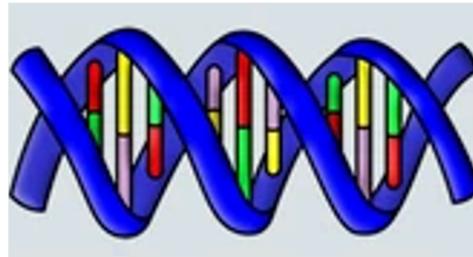
CTCGTCACCTCAC
| | | | | | | | | |
GAGCAGTGAAGTG



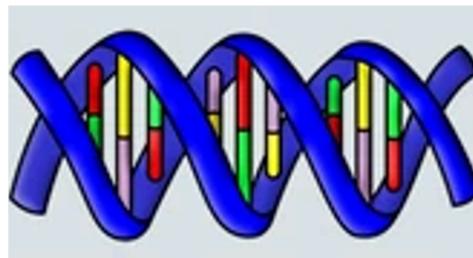
CTCCTCACCTCAC
| | | | | | | | | |
GAGGAGTGAAGTG

Double Helix Structure

- Each chromosome has two long strands of DNA.
- Homologous chromosome pair:



CTCGTCACCTCAC
| | | | | | | | | |
GAGCAGTGAAGTG



CTCCCTCACCTCAC
| | | | | | | | | |
GAGGGAGTGAAGTG

Human Genome

- 3 billion nucleotides (A,C,G,T) in the whole human genome.
 - Paired, double helix
- About 3 million of them differ between people (0.1% difference) - Genetic Variations.
- Most of these variations are in 'junk DNA'.
 - Not directly code for proteins.
 - May have regulatory or unknown functions.
- Minority of these variations change how products of genes (proteins) behave.
- Scientists study which variations are linked to specific traits or diseases.

Mutations

- Mutations are **changes** in DNA.

Reference Sequence:

ATG TCT GGA TAC CCG AAT GTC

ATG TCA GGA TAC CCG AAT GTC

↑
Substitution

ATG TCT TAC CCG AAT GTC

↑
Deletion

ATG TCT GTT AGC GGA TAC CCG AAT GTC

↑
Insertion

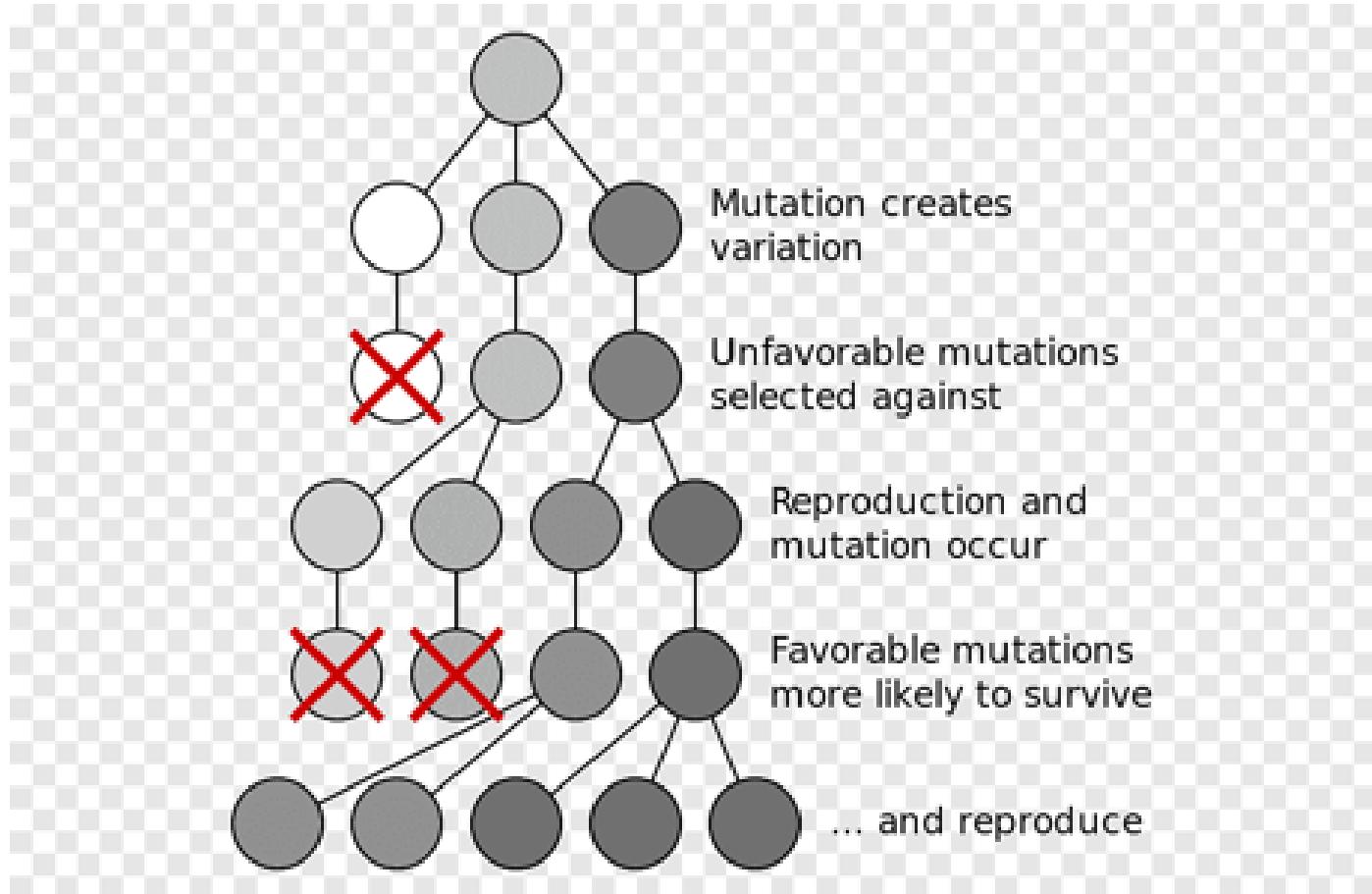
TGA CTA ATG TCT GGA TAC CCG AAT GTC

↑
Translocation (segment from another region)

Effects of mutations

- Mutations can be very detrimental to an organism.
 - May cause proteins to malfunction.
 - cells rely on the proteins may not function properly.
- Most of these deleterious mutations remain rare in the population, because they are rarely transmitted to the next generation.
- Many of the mutations have no effect.
 - e.g., TCT and TCA both code for the same amino acid (protein building block), so changing one to the other has no impact.

Mutations give rise to genetic variants

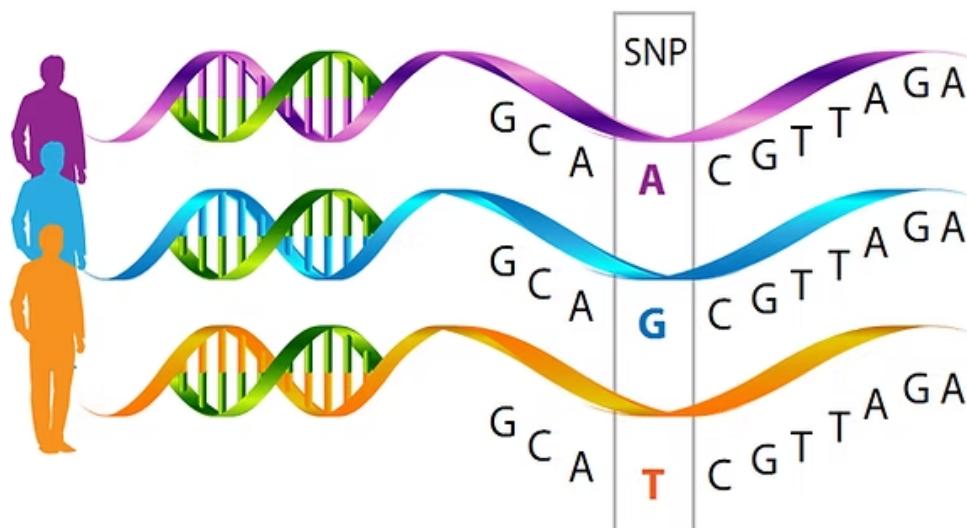


Genetic variants/Polymorphism

- A **polymorphism** is a part of DNA that can differ between individuals.
- These variations come from mutations that happened over long periods of human history.
- The different versions (or "states") of a polymorphism are called **alleles**.
- In statistical term: a polymorphism is a random variable and an allele is one of the outcomes in the sample space.

Types of genetic variants

- A **single nucleotide polymorphism (SNP)** is a type of genetic variation where a single nucleotide (A, C, G, or T) differs between individuals.
 - An **allele** at a SNP refers to one of the possible nucleotide bases — A, C, G, or T.
 - Appear about every 300 base pairs → ≈ 10 million SNPs.



Types of Genetic Variants

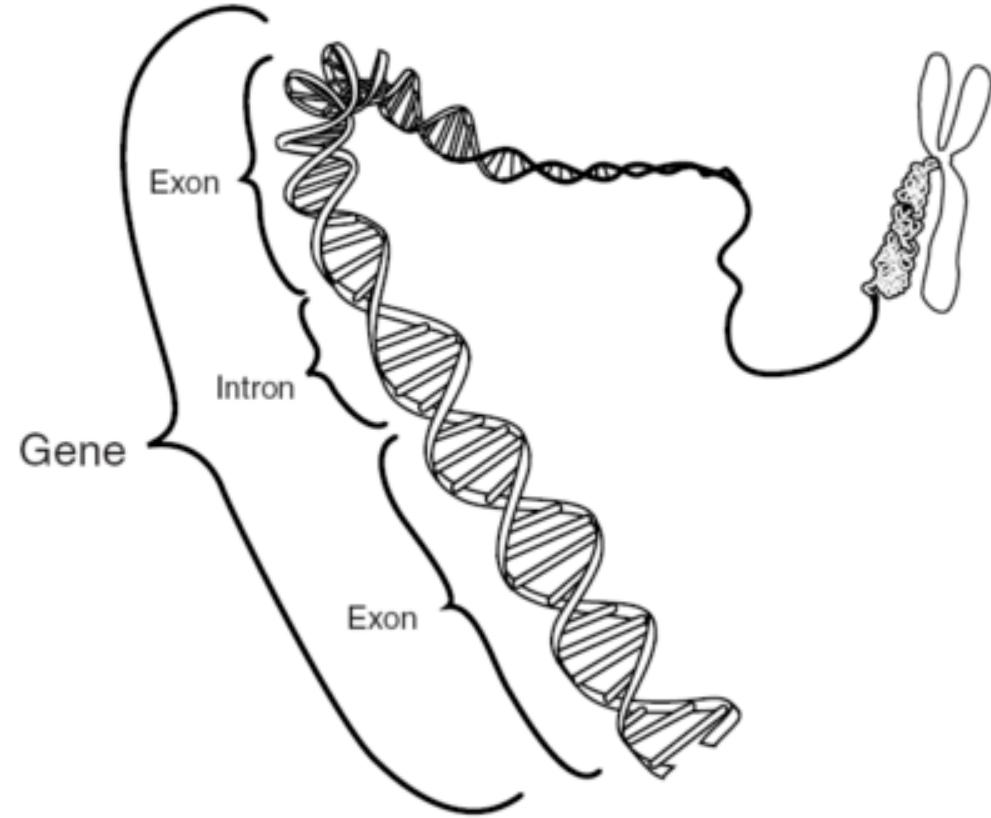
- **Variable number of tandem repeats (VNTR)**: Specific DNA sequences that are repeated immediately adjacent to each other a variable number of times.
 - e.g. 16, 14 and 11 repeats of CA.
 - **Microsatellites** consist of small sequences (1-6) which are repeated.
 - The number of repeats can vary widely from one person to the next, therefore they are used often in forensic DNA and paternity testing, and in linkage mapping.
- **Indels**: extra base pairs (between 1 and 1000) can be inserted/deleted in between two specific base pairs
- **Structural variants**: duplications, deletions, inversions, translocations
- **CNV (copy number variants)**: large insertions/ deletions

Types of Genetic Variants

Low-frequency variant	Indel polymorphism	Recombination hotspot	Repeat polymorphism
Common SNP			
G C T (G) C A		G A T C C ATTCATTC	
G C T (G) C A		G A T C C ATTCATTC	
G C T A (G) C T A		G A T C C ATTCATTC	
G C T (G) C A		G A T C C ATTCATTC	
G C T (G) C A		C C C T G ATTC	
G C T (G) C A		C C C T G ATTC	
G C T (G) C A		C C C T G ATTC	
A C T (G) A A		G A T C C ATTCATTC	
A C T (G) A A		G A T C C ATTCATTC	
A C T (G) A A		C C C T G ATTC	
A C T (G) A A		C C C T G ATTC	
A C T T (G) A A		C C C T G ATTC	
A C T (G) A A		C C C T G ATTC	
G G A () C T		G A T C C ATTCATTC	
G G A () C T		G A T C C ATTCATTC	
G G A () C T		G A C T C C ATTCATTC	
G G A () C T		G A T C C ATTCATTC	
G G A () C () G			ATTC
G G A () C T		C C C T G ATTC	

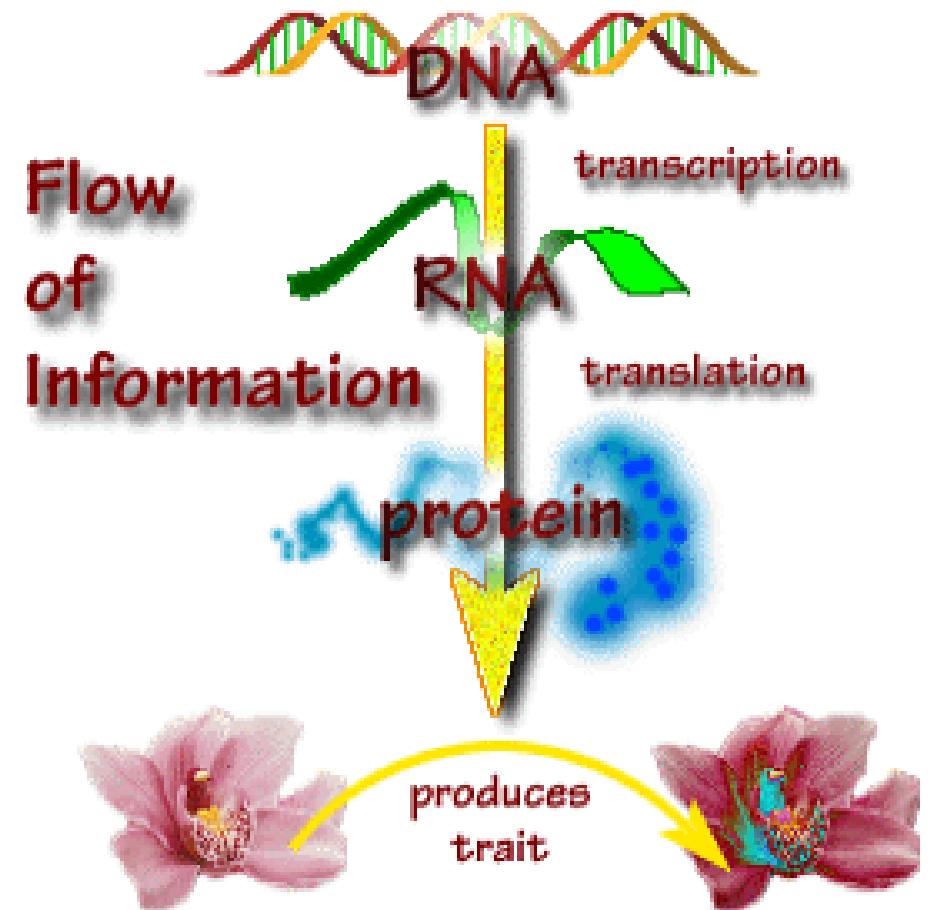
Genes

- A gene is an ordered sequence of nucleotides located in a particular position on a particular chromosome that **encodes a specific functional product** (a protein or RNA molecule).
- A gene is a segment of DNA consists of several coding segments (**Exons**), separated by non-coding sequences (**Introns**)
- Introns do not code for specific proteins, BUT, they are not junk and may regulate exons.



Genes

- Gene sizes vary from about 1K DNA base pairs to more than 1 million bp.
- About 20,000 - 30,000 genes throughout the genome.
- Genes themselves do not directly affect traits.
- Proteins - the coded product of genes - are the ones influencing traits.
- Through the processes of **transcription** and **translation**, information from genes is used to make proteins.



Proteins

- Proteins are strings of amino acids.
- There are **20 different amino acids** that are coded by codons.
- A **codon** is a sequence of **3 letters** (nucleotides) in DNA or RNA.
- There are 64 possible codons (4 bases: A, T, C, G — and combinations of 3)
- Multiple codons can code for the same amino acid.
 - For example: TCT and TCA both code for Serine.
 - This redundancy helps protect against mutations.

Codon Change Causes Sickle Cell Trait

- A Variant in the Hemoglobin Gene Causing Sickle Cell Anemia

HBB Sequence in Normal Adult Hemoglobin (Hb A):

Nucleotide	CTG	ACT	CCT	GAG	GAG	AAG	TCT
Amino Acid	Leu	Thr	Pro	Glu	Glu	Lys	Ser
	3			6		9	

HBB Sequence in Mutant Adult Hemoglobin (Hb S):

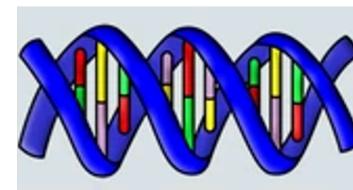
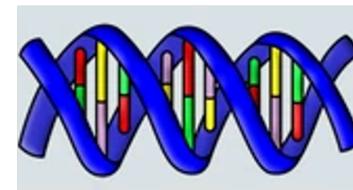
Nucleotide	CTG	ACT	CCT	GTG	GAG	AAG	TCT
Amino Acid	Leu	Thr	Pro	Val	Glu	Lys	Ser
	3			6		9	

Alleles and Genotypes

Genotype: the two alleles at each chromosomal location (a pair of chromosomes) for a given individual.

- Most SNPs are bi-allelic; two alleles can be either G-C or A-T (matching).
- Could code them A (say for G-C) and a (for A-T).

Individual 1:



Allele A

CTCGTCACTTCAC
| | | | | | | | | |
GAGCAGTGAAAGTG

CTCATCACTTCAC
| | | | | | | | | |
GAGTAGTGAAAGTG

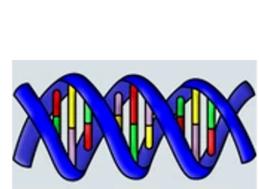
Allele a

The **genotype** at this SNP: **Aa**

Alleles and Genotypes

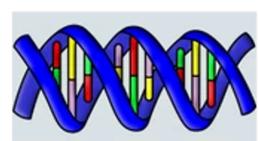
- A SNP with two alleles (A and a) has 3 possible (unordered) genotype: AA, Aa/aA, aa.
- **Homozygous** genotype: same allelic type (AA or aa);
- **Heterozygous** genotype: different allelic type (Aa/aA).

Individual 1:



Allele A

CTCGTCACCTCAC
GAGCAGTGAAGTG

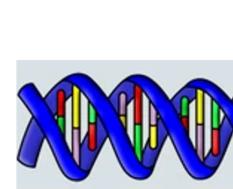


Allele a

CTCATCACCTCAC
GAGTAGTGAAGTG

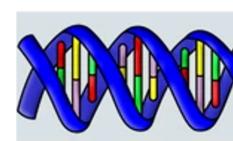
The **genotype** at this SNP: **Aa**

Individual 2:



Allele a

CTCTTCACTTCAC
GAGAAGTGAAGTG



Allele a

CTCATCACCTCAC
GAGTAGTGAAGTG

The **genotype** at this SNP: **aa**

Recap

- Human genomes and **paired** chromosomes
- DNA has double helix structure: a 4-letter (A-T, G-C) system.
- Variations/Mutations
 - polymorphisms/genetic variants \equiv discrete random variables
 - alleles \equiv outcomes of a random variable
 - **SNP** \equiv a r.v. with two outcomes
 - Microsatellite \equiv a random variable with typically 3-30 outcomes
- **Genotype** data of a polymorphism/genetic variant: paired alleles (from the paired chromosomes).

What's next

- Fundamental principles of population genetics
- Basic genetic models and genotype coding frameworks
- Principles of inheritance

What questions do you have about anything from today?