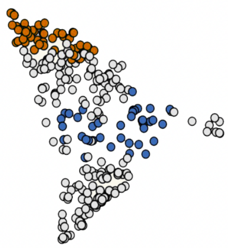
School of Molecular & Cellular Biology

MCB 545, Spring 2025

Functional Genomics in Principle and Practice
3 credit hours



Instructor

Kevin Van Bortle
B521 CLSL
kvbortle@illinois.edu

Class Meeting Schedule

M,W 10 – 11:20 AM
Location: Nevada Building Computer Lab (1203 ½ W. Nevada St.)
Office Hours: Fridays, 10 – 11 AM (virtual)

Course Overview and Description

This course introduces experimental and analytical foundations of functional genomics, tailored to experimental biologists who are interested in using high-throughput sequencing technologies to analyze function in animal genomes. The overarching structure of this course tasks students with exploring the regulation and function of specific RNA-binding proteins (RBPs) through integrative analysis of multiple genomic assays with programming in R. This course combines lectures, which cover basic principles (e.g. genome assembly, annotation, functional genomic methods, statistics for genomic data), with in-class programming and assignments. Students submit a written synthesis of their findings and underlying code at the conclusion of the course.

Course Prerequisites

Students are strongly encouraged to familiarize themselves with RStudio and the basics of programming in R prior to taking this class.

Student Learning Outcomes

At the end of the course, through assignments, discussions, activities and assessments, students will be able to:

- Understand basic principles of modern functional genomics methods, including current sequencing, computational, and statistical approaches
- Interpret common data analysis and visualization techniques and apply these approaches using programming in R
- Integrate multi-omic data to generate quantitative analyses related to the regulation and function of a specific gene of interest.

Course Text/Materials Information

Hands-on programming with R. Garrett Grolemund. O'Reilly Media. 2014
https://rstudio-education.github.io/hopr/basics.html
Student assignments will also include reading primary literature and reviews related to topics over the course of the semester.

Course Tools

MCB545 will utilize a Slack workspace for course communication between instructor and students (https://slack.com). Course material will be shared both through Slack and via GitHub (https://github.com/kvbortle/MCB545_FunctionalGenomics)

Grading Information and Breakdown

20% Class participation: includes attendance and participation (20 points total)
40% Graded homework assignments (40 points total, 10 points each)
15% Graded Midterm Exam (15 points total)
25% Final project assignment (25 points total)

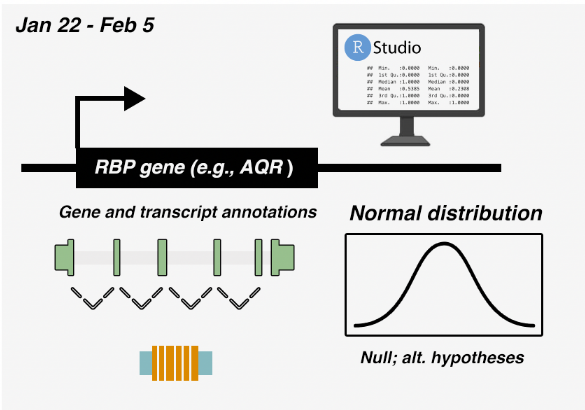
100 Total points

Grade format

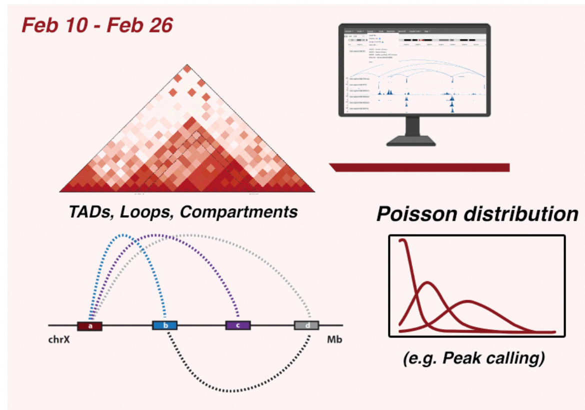
97–100%	(A+)	93–96%	(A)	90–92%	(A-)
87–89%	(B+)	83–86%	(B)	80–82%	(B-)
77–79%	(C+)	73–76%	(C)	70–72%	(C-)
67–69%	(D+)	63–66%	(D)	60–62%	(D-)
0–59%	(F)				

VISUAL COURSE OUTLINE (2025)

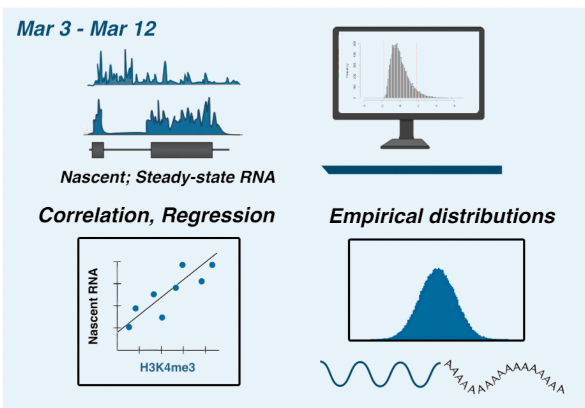
Module I. Intro to genomics and programming in R



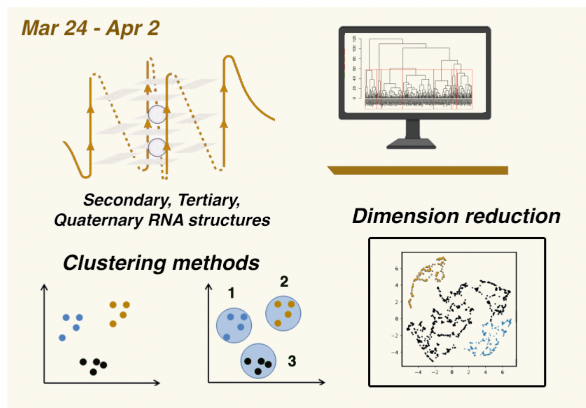
Module II. Chromatin architecture and regulation



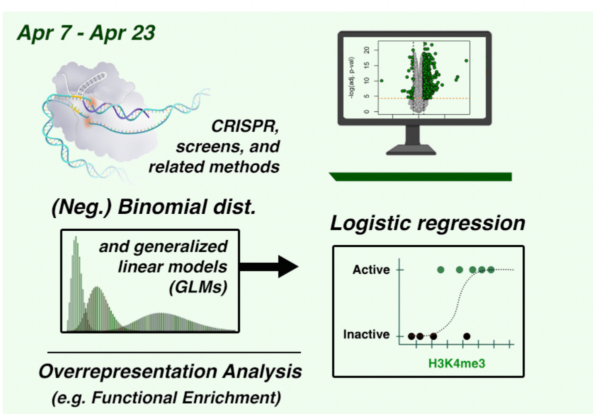
Module III. Transcription and RNA processing



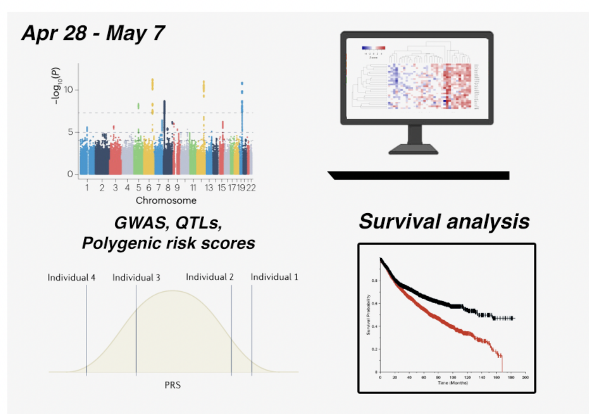
Module IV. RNA structure and translation



Module V. Perturbation and differential analysis



Module VI. Special topics (Health, disease, careers)



| COURSE CALENDAR (2025) |

SECTION I. INTRODUCTION TO GENOMICS | INTRO TO PROGRAMMING IN R

January 22	Genomics Topic: **Course overview | Intro to genomics | RBP selection** Week 1 Reading: *https://rstudio-education.github.io/hopr/basics.html* Assignment: Intro Poll; RNA-binding protein selection; install Rstudio
January 27	Genomics Topic: **Genome Assembly | Gene Annotation | Intro to IGV** Week 2 Reading: *Rood & Regev 2021 | Mudge and Harrow, 2016*
January 29	Exercise: Importing data in R | R functions | Plotting in R QMA Concept: **The Normal Distribution | Null and Alt. Hypotheses**
February 3	Genomics Topic: **Sequencing Platforms | Read Alignment** Week 3 Reading: *Shendure et al., 2017 | Sahlin et al., 2023*
February 5	Exercise: Survey of Gene & Transcript features and Distributions QMA Concept: **Maximum Likelihood | Expectation Maximization**

| Assignment # 1 - RBP gene and transcript annotation features: Due Feb. 14 (10 pts) |

SECTION II. CHROMATIN ARCHITECTURE AND REGULATION (IT'S A DNA WORLD)

February 10	Genomics Topic: **Replication, Chromatin, and TF Mapping** Week 4 Reading: *Hu & Stillman, 2023 | Klemm 2021 | Meyer & Liu 2014*
February 12	Exercise: Surveying the Regulome (Histones, Enhancers, Loops) QMA Concept: **The Poisson Distribution | Gene Network Analysis**
February 17	Genomics Topic: **Architecture: Loops, Domains, and Compartments** Week 5 Reading: *Kempfer & Pombo, 2020 | Jerkovic & Cavalli, 2021*
February 19	Exercise: Working with Genomic Intervals: Chromatin State QMA Concept: **Hidden Markov Models | Principal Component Analysis**
February 24	Genomics Topic: **Location: Subnuclear position (e.g. LADs, Speckles)** Week 6 Reading: *Shan et al., 2024 | Bhat et al., 2021*
February 26	Exercise: For loops and If statements: Gene Locations QMA Concept: **Empirical Null Distributions | Multiple Testing Correction**

| Assignment # 2 - DNA-related features of your RBP-encoding gene: Due Mar. 7 (10 pts) |

SECTION III. TRANSCRIPTION AND RNA PROCESSING (FROM DNA TO RNA)

March 3	Genomics Topic: **Transcription | RNA-seq methods** Week 7 Reading: *Stark et al., 2019 | Wissink et al., 2019*
March 5	Exercise: Integrating Gene Expression and Chromatin Data QMA Concept: **Linear Regression | Correlation Analysis**
March 10	Genomics Topic: **RNA processing and Splicing** Week 8 Reading: *Neil et al., 2022; Rogalska, Vivori, Valcarcel 2023; Mitschka & Mayr, 2022; Childs-Disney et al., 2022*
March 12	**| MIDTERM EXAM (15 pts) |**

March 15 - 23 Spring Break

SECTION IV. RNA STRUCTURE AND TRANSLATION (FROM RNA TO PROTEIN)

March 24	Genomics Topic: **Translation | RNA structure** Week 9 Reading: *Brar & Weissman, 2015 | Greener et al., 2022*
March 27	Exercise: RNA Intron Retention and rG4 profiling QMA Concept: **Clustering Methods**
March 31	Genomics Topic: **Protein-RNA & RNA-RNA Interaction Mapping** Week 10 Reading: *Hafner et al., 2021 (CLIP and complement. methods)*
April 2	Exercise: RNA-binding preferences and target RNA populations QMA Concept: **(Other) Dimension Reduction Techniques**

| Assignment # 3 - RNA-related features of your RBP-encoding transcript: Due Apr. 10 (10 pts) |

SECTION V. PERTURBATION AND DIFFERENTIAL ANALYSIS (PROTEIN “FUNCTION”)

April 7	Genomics Topic: **Gene Modulation (e.g. CRISPR) | Differential Analysis** Week 11 Reading: *Dowdy, 2017; Adli, 2018*
April 9	Exercise: Determination of RBP-sensitive genes QMA Concept: **Negative Binomial Distribution**
April 14	Genomics Topic: **Differential Analysis | Machine Learning** Week 12 Reading: *Van den Berge et al., 2019*
April 15	Week 12 Exercise: RBP target RNA population and sensitivity QMA Concept: **Logistic Regression | Generalized Linear Models (GLMs)**
April 21	Genomics Topic: **Functional Enrichment Analysis** Week 13 Reading: *Garcia-Campos et al., 2015 | Mubeen et al., 2022 | Wijesooriya et al., 2022 | Bild et al., 2006*
April 23	Week 13 Exercise: Gene Set Enrichment Analyses QMA Concept: **Fisher’s Exact Test | ECDF and K-S Test**

| Assignment # 4 - RBP-binding and target RNA regulatory prediction: Due May 2 (10 pts) |

SECTION VI. SPECIAL TOPICS (HEALTH, DISEASE, CAREERS)

April 28	Genomics Topic: **Genomics in Health and Disease** Week 14 Reading: *Malik et al., 2021; Uffelmann et al., 2021*
April 30	Exercise: Is my RBP a prognostic factor in cancer? QMA Concept: **Survival Analysis**
May 5	Genomics Topic: **Careers in Genomics**
May 7	**Course Review**

| FINAL REPORT DUE MAY 14 (25 pts) |

Assignments, due dates, and course expectations

MCB545 is geared towards the practical application of functional genomic data analysis and will function as a hybrid lecture and hands-on lab course series. Attendance and in-class participation (maximum 30 points, 30% of total) is critical for actively learning this broad subject area. Students must contact me immediately or in advance if it becomes necessary to be absent from class to identify a reasonable action plan. Lecture topics will be linked to learning programming in-class and through multiple homework assignments that will be submitted electronically (maximum 15 points, 15% of total). This course encourages team-learning, including regular communication and group work on the MCB545 Slack workspace. However, homework assignments must be written up and submitted independently. Presentation assignments will feature opportunities to analyze, discover, and finally present novel genomic findings through short presentations (maximum 30 points, 30% of total). Towards the completion of the semester, a final project assignment will require each student to independently apply data processing tools and data analysis methods taught during the semester, as well as integrate and synthesize all data analyzed throughout the course to establish a hypothesis about the regulation and function of a specific gene (maximum 25 points, 25% of total).

Academic integrity

Students are expected to be familiar with the code of policies and regulations applied in all instances of academic misconduct. Please refer to http://studentcode.illinois.edu, and, in particular, Article 1 part 4: http://studentcode.illinois.edu/article1/part4/1-401/

Accommodations

To obtain disability-related academic adjustments and/or auxiliary aids, students with disabilities must contact the course instructor and the Disability Resources and Educational Services (DRES) as soon as possible. To contact DRES, you may visit 1207 S. Oak St., Champaign, call 333-4603 (V/TDD), or e-mail a message to disability@uiuc.edu. http://www.disability.illinois.edu/.

Inclusive classroom statement

The effectiveness of this course is dependent upon the creation of an encouraging and safe classroom environment. Exclusionary, offensive or harmful speech, such as racism, sexism, homophobia, and transphobia, will not be tolerated and in some cases will be subject to University harassment procedures. We are all responsible for creating a positive and safe environment that allows all students equal respect and comfort. We expect each of you to help establish and maintain an environment where you and your peers can contribute without fear of ridicule or intolerant or offensive language.

Sexual misconduct policy and reporting

The University of Illinois is committed to combating sexual misconduct. Faculty and staff members are required to report any instances of sexual misconduct to the University's Title IX and Disability Office. In turn, an individual with the Title IX and Disability Office will provide information about rights and options, including accommodations, support services, the campus disciplinary process, and law enforcement options. A list of the designated University employees who, as counselors, confidential advisors, and medical professionals, do not have this reporting responsibility and can maintain confidentiality, can be found here: wecare.illinois.edu/resources/students/#confidential. Other information about resources and reporting is available here: wecare.illinois.edu.