Mathematics of infectious disease dynamics
MATH / PUBH-EPI 5421
Spring 2016

Instructor: Joseph Tien, tien.20@osu.edu. MW 536. Office hours: TBA.

Lectures: MW 12:45-2:05, Denney Hall 238.

Course website: Announcements will be posted at: `www.math.ohio-state.edu:/~tien.20/math5421`. Supplementary materials such as journal articles or other readings will be posted on Carmen.

Overview and course objectives: Mathematical models are an important tool for understanding infectious disease dynamics, and are increasingly used by public health workers and agencies for assessing disease risk and helping inform intervention strategies. This course provides an introduction to mathematical modeling of infectious diseases. We will learn techniques for building and analyzing disease models, and discuss calibration and comparison of models with data. Case studies will include measles, influenza, HIV, and others. This course is intended for a diverse audience, including students from mathematics, public health, and the biological sciences. Students who would benefit from the course include those who would like to use mathematical models in their own research or future employment (e.g. public health agencies at the state and federal levels; health care industry), and those who would like to be able to access the research literature on infectious disease modeling.

Prerequisites: 1 year of calculus, or instructor permission. Additional mathematical topics will be developed in the course as needed.

Textbook: None required; several suggested references are given below. Notes and additional readings will also be supplied.

- **Infectious disease models:** [2, 6, 13].
- **Stochastic processes:** [1].
- **Networks:** [18].
- **General mathematical biology:** [8, 7].
- **Programming:** [20] (Matlab).

Assignments: There will be roughly $4-5$ assignments. Assignments may include paper and pencil calculations, computational work, and exploration of infectious disease time series data.

Exams: There will be one midterm exam, administered in class on March 9 during the regular lecture time.

Final project: The course will culminate in a final project, conducted in teams of 2-4. I will help ensure that each team includes students with strong mathematical backgrounds, as well as students with strong public health or life science backgrounds. All students are expected to contribute significantly to their team project. I will provide suggestions for projects. Other topics are also possible – indeed, I encourage you to discuss with me ideas that you'd like to pursue. A write-up of the project ($\approx 10-15$ pages) will be due during exam period. Groups will also give oral presentations of their findings during exam period. All students are expected to attend the presentations and participate in a discussion of the projects.

Grading: Homework 30%, Midterm 20%, Final project 45%, Class participation 5%

Academic Integrity: Academic integrity is essential to maintaining an environment that fosters excellence in teaching, research, and other educational and scholarly activities. Thus, The Ohio State University, the College of Public Health, and the Committee on Academic Misconduct (COAM) expect that all students have read and understood the Universitys Code of Student Conduct and the Schools Student Handbook, and that all students will complete all academic and scholarly assignments with fairness and honesty. The Code of Student Conduct and other information on academic integrity and academic misconduct can be found at the COAM web pages (`http://oaa.osu.edu/coam.html`). Students must recognize that failure to follow the rules and guidelines established in the Universitys Code of Student Conduct, the Student Handbook, and in the syllabi for their courses may constitute Academic Misconduct.

The Ohio State University's Code of Student Conduct (Section 3335-23-04) defines academic misconduct as: "Any activity that tends to compromise the academic integrity of the University, or subvert the educational process. Examples of academic misconduct include (but are not limited to) plagiarism, collusion (unauthorized collaboration), copying the work of another student, and possession of unauthorized materials during an examination. Please note that the use of material from the Internet without appropriate acknowledgement and complete citation is plagiarism just as it would be if the source were printed material. Further examples are found in the Student Handbook. Ignorance of the Code of Student Conduct and the Student Handbook is never considered an "excuse for academic misconduct.

If I suspect a student of academic misconduct in a course, I am obligated by University Rules to report these suspicions to the Universitys Committee on Academic Misconduct. If COAM determines that the student has violated the Universitys Code of Student Conduct (i.e., committed academic misconduct), the sanctions for the misconduct could include a failing grade in the course and suspension or dismissal from the University. If you have any questions about the above policy or what constitutes academic misconduct in this course, please contact me.

Accommodation for Special Needs: If you need an accommodation based on the impact of a disability, you should contact me to arrange an appointment as soon as possible. At the appointment we can discuss the course format, anticipate your needs and explore potential accommodations. I rely on the Office of Disability Services for assistance in verifying the need for accommodations and developing accommodation strategies. If you believe you need accommodation and have not previously contacted the Office of Disability Services, I encourage you to do so. The office is located in 150 Pomerene Hall, 1760 Neil Avenue; telephone 292-3307, TDD 292-0901; more information is available at `http://www.ods.ohio-state.edu/`

Student Support and Assistance: A recent American College Health Survey found stress, sleep problems, anxiety, depression, interpersonal concerns, death of a significant other and alcohol use among the top ten health impediments to academic performance. Students experiencing personal problems or situational crises during the quarter are encouraged to contact the OSU Counseling and Consultation Services (292-5766; `http://www.ccs.ohio-state.edu`) for assistance, support and advocacy. This service is free to students and is confidential.

Course Content Outline:

1. Deterministic models.

- Basic SIR model. Introduction to compartmental differential equation models. Fixed points, linearization, stability. Basic reproduction number $\mathcal{R}_0$: biological and mathematical definitions. Next generation matrix. Initial epidemic growth rate, serial interval, and $\mathcal{R}_0$. Incidence functions. Herd immunity and critical vaccination threshold. Final outbreak size relation. Seasonality, oscillations.
  - Case studies: rotavirus in the U.S. [19], measles in the U.K. pre- and post-vaccination [5], global smallpox eradication [3, 9, 22], Ebola.
- Extensions: age structure, heterogeneity and multi-group models, vector-borne models.

- Age structure: Who acquires infection from whom (WAIFW) matrices; age profile for endemic vs. invading diseases with disease-induced immunity. Age-specific interventions.
    - Case study: Age-based vaccination strategies and flu policy in the U.S. [16].
- Multi-group models. Estimating mixing patterns. Core groups; disease hot spots.
    - Case study: Gonorrhea in the U.S. [12].
- Staged-progression models.

2. Stochastic models.

- Branching process basics; probability of extinction and $\mathcal{R}_0$; demographic fade-out; critical community size. Gillespie simulations.
- Distributions, linear chain trick, connections with deterministic systems.
- Case studies: contact tracing and SARS [15]. Measles in Iceland [4].

3. Disease dynamics on networks.

- Basic network terminology. Degree distribution and probability of disease outbreak. Social networks.
- Percolation, correlation equations, edge-based models.
- Case studies: SARS [17]. HIV (relevant portions of [10, 14]).

References

[1] L. J. S. Allen. *An introduction to stochastic processes with applications to biology.* CRC Press, 2nd edition, 2010.

[2] R. M. Anderson and R. M. May. *Infectious Diseases of Humans: Dynamics and Control.* Oxford University Press, Oxford, 1991.

[3] J. G. Breman and I. Arita. The confirmation and maintenance of smallpox eradication. *New England Journal of Medicine*, 303(22):1263–1273, 1980.

[4] A. D. Cliff, P. Haggett, J. K. Ord, and G. R. Versey. *Spatial diffusion: an historical geography of epidemics in an island community.* Cambridge University Press, 1981.

[5] David J.D. Earn, P. Rohani, B. M. Bolker, and B. T. Grenfell. A simple model for complex dynamical transitions in epidemics. *Science*, 287:667–670, 2000.

[6] O. Diekmann, H. Heesterbeek, and T. Britton. *Mathematical tools for understanding infectious disease dynamics.* Princeton University Press, 2012.

[7] L. Edelstein-Keshet. *Mathematical models in biology.* Number Book 46 in Clasics in Applied Mathematics. SIAM, 2005.

[8] S. P. Ellner and J. Guckenheimer. *Dynamic models in biology.* Princeton University Press, 2006.

[9] N. M. Ferguson, M. J. Keeling, W. J. Edmunds, R. Gani, B. T. Grenfell, R. M. Anderson, and S. Leach. Planning for smallpox outbreaks. *Nature*, 425:681–685, 2003.

[10] N. C. Grassly and C. Fraser. Mathematical models of infectious disease transmission. *Nature Reviews Microbiology*, 6(6):477–487, 2008.

[11] B. T. Grenfell, O. N. Bjørnstad, and J. Kappey. Travelling waves and spatial hierarchies in measles epidemics. *Nature*, 414(6865):716–723, 2001.

[12] H. W. Hethcote and J. A. Yorke. *Gonorrhea transmission dynamics and control*, volume 56 of *Lecture Notes in Biomathematics*. Springer-Verlag, 1984.

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[16] J. Medlock and A. P. Galvani. Optimizing influenza vaccine distribution. *Science*, 325(5948):1705–1708, 2009.

[17] L. A. Meyers, B. Pourbohloul, M. E. Newman, D. M. Skowronski, and R. C. Brunham. Network theory and SARS: predicting outbreak diversity. *Journal of Theoretical Biology*, 232:71–81, 2005.

[18] M. Newman. *Networks: an introduction*. Oxford University Press, 2010.

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[20] R. Pratap. *Getting started with Matlab: a quick introduction for scientists and engineers*. Oxford University Press, 2009.

[21] Y. Xia, O. N. Bjornstad, and B. T. Grenfell. Measles metapopulation dynamics: a gravity model for pre-vaccination epidemiological coupling and dynamics. *American Naturalist*, 164:267–281, 2004.

[22] J. A. Yorke, N. Nathanson, G. Pianigiani, and J. Martin. Seasonality and the requirements for perpetuation and eradication of viruses in populations. *American Journal of Epidemiology*, 109(2):103–123, 1979.