# MAE 598: Multi-Robot Systems
## *Syllabus for Fall 2016*

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**Lecture**: Tuesday/Thursday 9:00-10:15am, Wexler Hall (WXLR) A113

**Class Website**: Lecture notes/slides and links to readings will be posted on **Dr. Berman's teaching website:** http://faculty.engineering.asu.edu/acs/teaching
Course announcements, homework assignments and solutions, and grades will be posted on **Blackboard**. Announcements will also be sent via email.

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**Instructor**: **Prof. Spring Berman**

**Contact Info**: E-mail: spring.berman@asu.edu
Office: Engineering Research Center (ERC) 375
Office phone: 480-965-4431

**Office Hours**: Wednesdays 12:45am-1:45pm and Thursdays 10:30-11:30am in ERC 375
Other times by appointment (schedule by e-mail to spring.berman@asu.edu)

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**Textbooks:** Some course readings will be drawn from the following (free) texts:

**(1)** "Lecture Notes on Mathematical Systems Biology," by Eduardo Sontag, 2015
Available for download here: http://www.mit.edu/~esontag/FTP_DIR/notes_biomath.pdf

**(2)** Graph Theoretic Methods in Multiagent Networks, by Mehran Mesbahi and Magnus Egerstedt, 2010
Available through the ASU Libraries website, https://lib.asu.edu/

**(3)** Distributed Control of Robotic Networks, by Francesco Bullo, Jorge Cortes, and Sonia Martinez, 2009
Available for download here: http://coordinationbook.info/download.html

**(4)** Convex Optimization, by Stephen Boyd and Lieven Vandenburghe, 2004
Available for download here: http://web.stanford.edu/~boyd/cvxbook/

**(5)** Planning Algorithms, by Steven LaValle, 2006
Available at this website: http://planning.cs.uiuc.edu/

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**Course Description**: This course combines seminar-style discussions of research on multi-robot systems with instruction on the theoretical foundations of this research. Students will complete homework assignments to gain practice using the techniques taught in class, and they will give presentations on the material and engage in class discussions to advance their critical thinking and communication skills. They will have the opportunity to further explore a particular course topic in a final project.

**Course Objectives:** Students will learn approaches to modeling, analyzing, and controlling multi-robot systems for a variety of objectives using stochastic processes, graph theoretic methods, geometric concepts, dynamical systems theory, control theory, and optimization techniques. Students will become familiar with seminal research in the field of multi-robot systems and apply the tools they have learned in a culminating research project. Students will be required to use MATLAB to solve problems throughout the course. MATLAB is available at: http://citrix.asu.edu

**Enrollment Requirements:** Students should ideally be familiar with the fundamentals of linear algebra, differential equations, dynamical systems, control theory, probability theory, and MATLAB. Supplementary materials will be provided on these topics.

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**Homework**:
There will be about 4 homework assignments throughout the semester. Homework should be turned in **at the beginning of class** on the due date. Unless a student has obtained special permission for extraordinary circumstances, late homework assignments will not be accepted.

**In-Class Presentations:**
Students will pair up, and each pair will be assigned to give a 15-minute presentation about a particular research publication on a specified date. Each student will talk for half of the presentation and answer any questions from the class afterward. The presentation can be in the form of slides or a discussion using the whiteboard, and it should include a summary of the paper and its results, as well as the paper's strengths, weaknesses, and any points needing clarification. Students may include videos and any other interesting supporting information in support of the presentations.

**Final Project:**
Students will complete a final project on a topic of their choosing that makes use of the theoretical material taught in the course. The project may incorporate simulation and/or experimental studies if desired, and the student(s) must describe the work in a detailed final paper (guidelines for the paper will be given in class). Students may work alone on the project or pair up. Students who pair up must scale the scope of their project appropriately and state the contribution of each team member. Students will submit a project proposal to the instructor by the middle of the semester and receive feedback before they begin their project.

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**Grading Policy**:

- After graded work is returned to students, no grading inquiry will be considered for 24 hours. After that period, students have **one week** from the day that their work is returned to contact the instructor regarding the grading of a specific homework assignment or exam. After the one-week period, no grading inquiry will be considered. Please note that by contesting the grading of a homework assignment or test, you are agreeing that the entire assignment or test is subject to be re-graded.

- Students are responsible for checking the Blackboard website to make sure that it has the correct grade information. Students are encouraged to keep all graded assignments since grades cannot be corrected without physical proof that an error was made.

- After the final exam, no request for a grade upgrade will be considered. Students are responsible for earning their final grade.

- **Grade of Incomplete:** An "incomplete" may be awarded only in cases when a student, who is otherwise performing satisfactorily, cannot complete final course requirements, such as a final exam or final project, due to circumstances beyond the student's control (such as illness or family emergency). Such circumstances must be documented. The student must have completed most of the course requirements. Incompletes will be approved only within the last one or two weeks of the semester and, in any case, never prior to the final semester withdrawal date. Incompletes cannot be requested after the time of the scheduled final exam for the course. To request a grade of incomplete, the student must formally apply to the instructor using the university's "Incomplete Grade Request" form. Requests must be submitted to the student's advisor prior to the final grade due date and are subject to final approval by the program.

*Composition of course grade:*

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| Homework assignments | 45% |
| Presentation, class participation | 10% |
| Final project | 45% |

*Letter grade rubric:*

*(Note: these are approximate boundaries between grades)*

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|---|---|
| A+: | ≥ 95 |
| A: | ≥ 85 and < 95 |
| A-: | ≥ 80 and < 85 |
| B+: | ≥ 77.5 and < 80 |
| B: | ≥ 72.5 and < 77.5 |
| B-: | ≥ 70 and < 72.5 |
| C+: | ≥ 67.5 and < 70 |
| C: | ≥ 60 and < 67.5 |
| D: | ≥ 50 and < 60 |
| E: | < 50 |

**Academic integrity policy:**

- Cheating on homework is **unacceptable**. While students may discuss homework assignments with each other, the work that each student submits must be entirely his/her own. Plagiarism is the submission of unreferenced content that was not the product of your original thought but which you are claiming as your own. Group homework, including writing and submitting multiple copies of communal MATLAB code, is not allowed.
- Copying on the homework will result in a **zero** for the homework portion of the total grade; plagiarism on the project will result in an **E** for this class. Suspected cases of academic dishonesty will be reported to the Office of Academic and Student Affairs. See the ASU Academic Integrity Policy at http://provost.asu.edu/academicintegrity for more details.

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**Other Notes**:

- Students are expected to regularly attend lectures and are advised to take advantage of office hours. Please schedule an appointment with me during office hours if you have any questions, concerns, or if you have a disability that will require accommodations during this class.
- Absences will be excused for: (a) official university-recognized religious holidays (see ACD 304-04); (b) university-sanctioned events and activities (see ACD 304-02), such as participating in officially recognized sporting events and representing ASU at student conferences. In these cases, students will be given the opportunity to make up exams and other graded work. The university requests that students who are ill remain away from campus in order to prevent the spread of infectious disease. Students with documented illness will be given alternative grading options.
- Use of cell phones is not permitted in the classroom. Recording devices are allowed, but please note that lectures and other course content are copyrighted materials. Students may not sell notes or recorded content taken during the course.
- Disruptive or threatening behavior will be handled according to Section 104-02 of the Student Services Manual. All incidents and allegations of violent or threatening conduct by an ASU student (whether on- or off-campus) must be reported to the ASU Police Department and the Office of the Dean of Students.
- Students requesting accommodations for a disability, including additional time or resources for taking exams, must be registered with the Disability Resource Center (DRC, http://www.asu.edu/studentaffairs/ed/drc/, Phone: 480-965-1234; TDD: 480-965-9000) and submit appropriate documentation from the DRC to me.
- Information in this syllabus, other than grade and absence policies, may be subject to change with reasonable advance notice.

# Tentative Schedule for MAE 598: Multi-Robot Systems – Fall 2016

Electronic copies of lecture notes and links to readings will be provided on Dr. Berman's website:
http://faculty.engineering.asu.edu/acs/teaching
**Red = Student presentations**

| # | Date | Topics | Readings | Assignment |
|---|---|---|---|---|
| 1 | Aug. 18 | Syllabus, applications, state of the art, open challenges | [R1]-[R4] | **Choose presentation partner** |
| 2 | Aug. 23 | Multi-robot representations, control architectures, simulation environments, and testbeds | [R5]-[R7] | |
| 3 | Aug. 25 | Stochastic models and controllers for individual robots | [R8]; Sections 1, 2, 4 of [R9]<br>**Optional:**<br>Sontag 4.1, 4.2, 4.4.1-4.4.3 | |
| 4 | Aug. 30 | Master equation and mean-field (ODE) abstractions of population dynamics | | |
| 5 | Sept. 1 | Formulations of ODE abstractions of population dynamics | Sontag 2.6 intro, 2.6.1, 2.6.2, 2.6.4; [R10] up to Section 4.3, [R11], [R12]<br>**Optional:** Sontag 4.4.7 | |
| 6 | Sept. 6 | Analysis of ODE abstractions of population dynamics | [R13], [R14] | |
| 7 | Sept. 8 | Control and optimization of ODE abstractions;<br>**George Karavas and Jeff Skidmore** | [R15], Sections 1 and 2 and Appendix A of [R16] | **HW 1 assigned** |
| 8 | Sept. 13 | Self-organization in biological collectives;<br>**Mohammad Alzorgan and Zahi Kakish** | [R17] | |
| 9 | Sept. 15 | Self-organization in biological collectives;<br>*Guest lecture:* Prof. Ted Pavlic | Sontag 3.1.1-3.1.5, 3.1.7-3.2.2, 3.2.6-3.2.7 | |
| 10 | Sept. 20 | PDE abstractions of population dynamics;<br>Graph-based network models | [R18], [R19]<br>**Optional:** Mesbahi Ch. 2, 3 | |
| 11 | Sept. 22 | Graph-based network models | [R18], [R19], [R20]<br>**Optional:** Mesbahi Ch. 2, 3 | **HW 1 due (on Sept 23)** |
| 12 | Sept. 27 | Consensus, agreement, and synchronization in networks; **Robert Holgate and Nathan Cahill** | [R21] | |
| 13 | Sept. 29 | Consensus, agreement, and synchronization in networks; **Ethan Fisher and Hosain Bagheri** | [R22]; Mesbahi Ch. 4.1, 4.2, Appendix A.3.1 | |
| 14 | Oct. 4 | Formation control and flocking;<br>**Sean Sosa and Sardar Suhailjeet Singh** | [R23] | |
| 15 | Oct. 6 | Formation control and flocking;<br>**John Wilson and Adam Miyai** | [R24]<br>**Optional:** Bullo pp. 94-124 | **HW 2 assigned (by Oct. 9)** |
| | Oct. 11 | **No class – Fall Break** | | |
| 16 | Oct. 13 | Geometric representations for multi-robot systems | [R25] | |
| 17 | Oct. 18 | Geometric representations for multi-robot systems;<br>Coverage control; **Cheng Lu and Sujeet Krishnan** | [R26] | |
| 18 | Oct. 20 | Coverage control;<br>**Iat Hou Fong and Zhi Qiao** | [R27]<br>**Optional:** Boyd 3.1-3.2 | |
| 19 | Oct. 25 | Coverage control; Connectivity maintenance;<br>**Karthik Ramagiri and Himangshu Kalita** | [R28], [R32]<br>**Optional:** Boyd 4.1-4.3 | |
| 20 | Oct. 27 | Connectivity maintenance;<br>**Sameer Shailesh Ratnaparkhi and Karan Subhash Bhutada** | [R29], [R30] | **HW 2 due** |

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| 21 | Nov. 1 | Potential fields; **Yixuan Sheng and Sara Mantlik** | [R31] | |
| 22 | Nov. 3 | Potential fields; **Gordon Ssegimu and Graham Dektor** | [R33]<br>**Optional:** [S4] | **Project Proposal due** (Nov. 5, 11:59pm) |
| 23 | Nov. 8 | Concepts from topology; Motion planning for robotic swarms; **Krishna Kumar Balasubramanian and Manikandan Bodapati** | [R34] | |
| 24 | Nov. 10 | Concepts from topology; Mapping with robotic swarms; **Prajeet Krishnan and Vaibhav Deshmukh** | [R35] | |
| 25 | Nov. 15 | Cooperative manipulation; **Aniket Shirsat and Mahdi Ilami** | [R36]<br>**Optional:** [S6] | **HW 3 assigned** (Nov. 14) |
| 26 | Nov. 17 | Cooperative manipulation; **Shaopang Han and Andrew Thoesen** | [R37]<br>**Optional:** [S7] | |
| 27 | Nov. 22 | Collective construction; **Nirangkush Das and Haoyang Wei** | [R38] | |
| | Nov. 24 | **No class – Thanksgiving** | | |
| 28 | Nov. 29 | Collective construction; **Nolan Scharn and Sai Nizampatnam** | [R39], [R40]<br>**Optional:** [S8], [S9], [S10] | |
| 29 | Dec. 1 | Self-assembly and assembly; micro-nanorobotic swarms; ethical issues; **Abhishek Garg and Jonathan Chen, Ao Li and Hao Wu** | | **HW 3 due** (Dec. 2, 11:59pm) |
| | Dec. 6 11:59pm | | | **Final projects due** |