

Graduate Option Regulations and Guidelines:

Control and Dynamical Systems

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1 Introduction

This document describes the requirements for obtaining a graduate degree in Control and Dynamical Systems at Caltech. It is intended to complement the Caltech Catalog by giving additional information about option regulations and standard procedures.

There are three examinations which are required to obtain a Ph.D. in CDS. The first is the *Qualifying Exam*, given in the first year of study and intended to evaluate the student's expertise in mathematics, control, and dynamical systems. This exam is administered at the beginning of the second term and may be retaken in the third term if necessary. The *Candidacy Exam* is normally given at the end of the second year and is used to evaluate a student's research abilities. Upon passing the Candidacy exam, the student is admitted to candidacy, a key step in obtaining a Ph.D. The final exam is the *Ph.D. examination* (or thesis defense) and is given after completion of the Ph.D. dissertation.

A rough outline of the typical schedule for the first two years of study in CDS is the following:

- Year One
 - Complete CDS required courses (140, 201, 202) + focus requirement
 - Take a control class the first term (usually CDS 110 or 212) and pass the CDS Qualifying Exam
 - Take additional classes to fill out the schedule (at least 36 units per term)
 - Find a research advisor
- Year Two
 - Complete additional coursework in CDS (45 units total)
 - Take and pass the CDS Candidacy Exam
 - Advance to Candidacy for the Ph.D.

Note that most students will begin doing research in the summer of their first year in residency, in preparation for the Candidacy Exam. It is therefore essential that students find a research advisor no later than the end of third term and select an initial research project to form the basis of the Candidacy Exam.

The remainder of this document contains detailed descriptions of the requirements and procedures for completing the Ph.D. program in CDS. If you have any questions, you should consult your advisor or the CDS Option Representative.

2 The Ph.D. Program

2.1 Aims and Scope

The option in control and dynamical systems (CDS) is open to students with an undergraduate degree in engineering, mathematics, or science. The qualifications of each applicant will be considered individually, and, after being enrolled, the student will arrange his or her program in consultation with a member of the faculty. In some cases the student may be required to make up undergraduate deficiencies in engineering science courses.

The CDS option emphasizes the interdisciplinary nature of modern theory of dynamical systems and control. The curriculum is designed to promote a broad knowledge of mathematical and experimental techniques in dynamical systems theory and control. In addition to taking courses in the CDS option, students must select a focus area (see below).

2.2 Coursework

Upon admission each student will be assigned an adviser in the option and a committee of three members, chaired by the adviser, which will approve the initial course of study by the student. Each prospective Ph.D. student will meet with their advisor to evaluate the student's background, relative to that expected at the Ph.D. level, in the areas of mathematics, control, and dynamical systems. The chief intention of these consultations is to set up a course program for the first year of study. The adviser will be replaced by a research adviser when the direction of specialization is determined, not later than the beginning of the second year.

The following course requirements must be satisfied in order to obtain a Ph.D. in Control and Dynamical Systems:

- Complete the following required courses: CDS 140ab, CDS 201, CDS 202;
- Complete the focus requirement, consisting of at least 27 units in a particular area outside of CDS. Courses taken to satisfy the focus must represent a coherent program of advanced study in the chosen area. Possible areas include fluids, vehicles, vibrations, transport phenomena, process design, analog VLSI, propulsion, robotics, turbomachines, power electronics, micromachines, economics, and neurobiology. The program of study must be approved by the student's counseling committee and the option representative.
- Complete an additional 45 units in CDS or other advanced courses in dynamical systems and/or mathematics;

The student's counseling committee will be the judge of the completion of the focus requirement, necessary before the candidacy examination.

Courses used to satisfy the CDS requirements cannot be taken P/F unless they are not offered for grades.

2.3 Research Advisor

Shortly after the beginning of the first term, graduate students are encouraged to meet with faculty to discuss proposed research and generally attain information for choosing a research advisor. Students are responsible for finding a faculty member who agrees to supervise their research no later than the end of third term of the first year.

2.4 Oral Qualifying Exam

Each student is required to take a subject oral qualifying examination at the beginning of the second quarter in residence, the purpose of which is to examine expertise in mathematics, control, and dynamical systems. The exam covers the material taught in the first term of CDS classes (typically CDS 201, CDS 110/212 and CDS 140). Students may petition the faculty to replace one of these areas with an outside area. Petitions are due no later than the last day of classes of the term preceding the exam.

Three types of decisions will be possible: *pass*, *provisional pass*, *fail*. A student with a *pass* or *provisional pass* is permitted to begin his or her Ph.D. research. However, a student with a *provisional pass* will usually be required to satisfy some additional requirements, such as successful completion of specified coursework. Students who fail the oral subject exam may be permitted to repeat the exam (or part of the exam) once in the spring term, but this will occur only upon recommendation of the relevant examination committee(s).

The format of the oral qualifying exam is described in Section 3.

2.5 Candidacy Exam

Prior to admission to candidacy for the Ph.D. degree, a student is required to pass the candidacy examination. This exam consists of two parts: a *research progress report* and an *oral examination* based primarily upon the content of the report. A student who fails to pass the candidacy exam according to the timetable and procedures described below will *not* be permitted to register in any subsequent terms, except for the purpose of completing work toward the M.S. degree, and then only with the permission of the option representative and the research advisor.

The research progress report required for admission to candidacy must be submitted to the faculty *before* the end of the second term of the second year in residence. The report is to be based upon the Ph.D. research project and is expected to exhibit a professional quality of exposition. As a guide, the report should outline the research problem, the progress of the student at the time of writing, and the areas proposed for future study. It is also important that the report provide clear evidence of the student's understanding of the motivation for the research problem and its relevance to the general research area, as well as an appreciation of relevant techniques and methodology. The student should strive for a precise and concise format. Normally, the text itself should not exceed 20 pages.

The research progress report will be approved based upon the recommendation of an oral examination committee; the committee will consist of no less than three faculty members, including the research advisor and at least one additional member of the CDS faculty. The choice of the oral

exam committee will be made by the student and his or her research advisor, and must be approved by the Option Representative. It is the responsibility of the student to obtain approval from each proposed committee member for the time and date of the oral exam. The list of the recommended exam committee members must be submitted at the same time as the research progress report, and the exam is normally scheduled within one month of submitting the report. The exam committee may require revision of the report, and possibly a reexamination. In any case, an *approved* report, including any revisions, modifications etc., must be submitted to the CDS secretary *before the end* of the third term of the second year in residence. Exceptions to the rule may be granted by the faculty in unusual circumstances such as extended illness or a change of research advisors, but only upon written petition by the student to the graduate studies committee *prior* to the end of the first term of the second year in residence.

See Section 4 for more details on the procedure for advancement to candidacy.

2.6 Appointment of Thesis Review Committee

After a student passes the second-year candidacy exam, a faculty committee known as the *thesis review committee* will be appointed to review periodically the student's progress. This committee will serve not only as overseers of research progress during the student's Ph.D. residency, but will also contribute to the intellectual development of the student through sustained interaction. Usually, the thesis review committee will include members of the candidacy committee, and will be appointed by the Option Representative based upon the student's recommendation of proposed members. It is the responsibility of the student to obtain the agreement of each proposed member prior to submitting the list. Each student should endeavor to form the committee as soon as possible after passing the candidacy exam, but no later than one month prior to the beginning of the third year in residence. This committee will meet with the student before fall registration each year, either as a group or individually, to review progress, suggest improvements in research etc.

2.7 Final Thesis and Oral Exam

As a final step in the Ph.D. program, the student is required to submit a satisfactory thesis and pass a final oral examination. This exam will be preceded by a seminar which will be open to the general public. "Ph.D. Examination Procedures" describes the procedures in detail.

3 CDS Qualifying Exam Procedures

3.1 Format and Content of the Exam

Each student is required to take a subject oral qualifying examination at the beginning of the second quarter in residence, the purpose of which is to examine expertise in mathematics, control and dynamical systems. The exam covers the material taught in the first term of CDS classes (typically CDS 201, CDS 110/212 and CDS 140a). Students may petition the faculty to replace one of these areas with an outside area. Petitions are due no later than the last day of classes of the term preceding the exam.

Two and one-half (2-1/2) hours are allotted to the exam. During the first 90 minutes you will be given a written copy of the exam questions, and will have the opportunity to prepare your answers; during the second 60 minutes you will answer the questions orally at the direction of the committee. While preparing your answers, you are not allowed to consult references of any kind. All information that we do not expect you to know (or be able to derive) will be supplied as part of the question. You should strive to present your answers in a concise and incisive manner. Due to scheduling, we will not be able to extend the answer period beyond 60 minutes.

To determine potential subject matter, you should feel free to discuss relevant references, etc. with members of the faculty; however, do not expect the questions to be derived from any specific reference. Also, do not expect (or ask for) information about the nature or topics of the questions themselves.

3.2 Exam Scheduling

The Qualifying Exam will take place at the beginning of the second term in residence. All first-year CDS students will receive a scheduling form at the end of first term, which must be filled out and returned to the Option Secretary no later than the end of first term (i.e., the last day of finals). Petitions to replace one of the standard subject areas with an outside subject area must be submitted no later than the last day of classes of first term.

The schedule for exams will be available by the end of the first week of classes in second term, and exams will normally be scheduled beginning in the second week of the term. The results of the exam will be announced a few days after the completion of the exam. Upon recommendation of the examining committee, students who fail the exam will be given one additional opportunity to take the exam, typically at the beginning of spring term.

4 Procedures for Advancement to Candidacy

4.1 Requirements for Candidacy

To be recommended for candidacy for the doctorate degree, the applicant, in addition to demonstrating understanding and knowledge of fundamentals at the first-year Qualifying Examination, must give satisfactory evidence of ability to carry out research in his or her primary field of interest. Hence, the applicant must submit and have approved a written Research Progress Report. In most cases, approval of the written report will be based on a satisfactory oral defense of its contents. A student who fails to satisfy the requirements of the Division for candidacy by the end of the third term of the second year in residence at the California Institute of Technology will not be allowed to register in a subsequent academic year except by special permission of the Division.

4.2 Procedures for scheduling and taking the exam

1. Select a tentative date (determined by the candidate and his or her research advisor) and an examining committee of at least three members. Check with the CDS Secretary to avoid time/place conflicts. Then check with members of your committee to see that the date is satisfactory. The committee must consist of at least two CDS faculty members and must be approved by the Option Representative before the exam is scheduled.
2. Obtain a *Candidacy Form* for the Degree of Doctor of Philosophy from the CDS Secretary. Enter your name, major, and minor (if you choose to have one) at the top of the Candidacy Form. If you choose to pursue a minor, fill in Section II6; if you do not pursue a minor, fill in Section II5 with the courses taken outside of CDS (see below). Get proper approval signatures and return the form to the CDS Secretary.
3. Prepare four copies of your Research Progress Report and deliver a copy to each of your committee members no later than *two weeks* prior to your examination.

This report should describe concisely the present state-of-the-art of your research topic, your progress to date, your proposed research, and the nature of the contribution which you expect to make in the general problem area. All of this should not exceed *twenty pages, double-spaced and typed*.

4. When the Research Progress Report is satisfactory, the members of the examining committee will sign the Candidacy Form. All forms will be returned to the CDS Secretary by the committee chairman immediately after the examination. You must fill out information in Section II, and take it to the Registrar's Office for signature, and then to the Option Representative for completion of Section V. Then obtain the Division Chairman's signature and take the form to the Graduate Office for your file there. You will be notified later by the Dean of Graduate Studies that you have been admitted to Candidacy for the Degree of Doctor of Philosophy.

5 Ph.D. Examination Procedures

The final Ph.D. exam will consist of a defense of the candidate's thesis research. In addition to the formal exam, each candidate is required to present a seminar (open to the public) on his or her work; this seminar will be scheduled in the Caltech Calendar as a regular CDS Seminar. The exam and seminar must be held at least two weeks before the degree is conferred.

5.1 Procedures for Processing Necessary Forms

1. At least *three weeks* prior to the exam date, obtain the following forms from the Graduate Office:
 - (a) Petition for Exam
 - (b) Application for Approval of Thesis
 - (c) Microfilm Agreement
 - (d) Survey of Earned Doctorates.

The date of the Ph.D. exam and the committee members will be determined by you and your research advisor and must be approved by the Option Representative. Normally the committee will consist of four faculty members, including your advisor and at least one other CDS faculty member. Non-Caltech experts in your area can be allowed, if approved by your advisor and the CDS option representative. Check with members of your committee for agreement on the date and time of the exam. Once a definite date and committee are set, the CDS Secretary will send a confirming memo to the committee members.

2. Fill out and sign the top portion of the *Application for Approval of Thesis*.
3. Complete the first page of the *Petition for Exam*; have the Registrar complete and sign Part I of page 2. Complete Part II of page 2, obtain the Divisional Chairman's signature, and deliver the form to the Graduate Office. The Petition will remain there until just before your exam when you should return it to the CDS Secretary.

5.2 Procedures for Submitting the Ph.D. Thesis

1. *At least two weeks prior to your exam*, supply each member (four are needed, one of whom can be a qualified Ph.D. from off-campus) of your committee with a copy of your thesis. The Petition and Approval of Thesis forms will not be signed at the time of the exam unless the thesis requires no changes. If corrections or revisions are required, it is your responsibility to:
 - make the necessary corrections or revisions;
 - submit the revised thesis to members of your examining committee; and
 - secure committee signatures on the Petition of Approval of Thesis forms after the acceptance of the corrections or revisions.
2. Submit one copy of your thesis to the Graduate Office for proofreading. This should be done at the same time the thesis is submitted to your committee members. (If corrections or

revisions are required, the thesis must be proofread a second time.) You will be notified as soon as the proofreading is complete (usually a couple of days).

3. After the exam is passed in all respects and the committee has signed both the Petition and Approval of Thesis forms, obtain the signature of the Option Representative of your subject minor, if appropriate, and return the form to the Graduate Office.
4. Submit the thesis to the Graduate Office following the regulations and directions that can be obtained from the Office of the Dean of Graduate Studies. Their website also contains valuable information that can be of assistance in preparing for your final Ph.D. Examination.

6 Transferring into CDS from Another Option

Students wishing to switch into CDS from another option must do so before the end of their second year of residence at Caltech. Students must satisfy all option course requirements and must pass the candidacy exam in order to be officially admitted into the CDS Ph.D. program. In addition, the student is expected to take the CDS qualifying exam no later than the first year of study after transferring into the CDS option.

The procedure for switching into CDS is as follows:

1. The student should submit a written request to the Option Representative to consider admission into the CDS option. Under normal circumstances, this request must be received no later than the admissions deadline for incoming graduate students (December 15) for admission in the following year.
2. The Admissions Committee will consider applications for transfer using the same criteria as outside admission into the CDS program. Transfer students will be notified of admission by the usual admissions response deadline (March 31).
3. Transfer students who are admitted into CDS must accept or decline admission no later than the usual admissions deadline (April 15). If admitted, the student may either transfer immediately or defer admission until the beginning of the academic year.
4. Financial aid for transfer students will be described in the letter of admission. Aid is not usually available until the beginning of the next academic year.

7 The M.S. Program

Students will be admitted to the option who expect to pursue the Ph.D. degree. The master's degree may be awarded in exceptional cases. The awarding of this degree requires fulfilling the Institute requirements for a master's degree, satisfying the engineering focus requirements, and receiving a recommendation for awarding of the degree from the counseling committee.

The M.S. program, unlike the Ph.D., is based primarily upon the successful completion of coursework. This coursework must include at least 135 units in order to satisfy Institute requirements, with the following core courses:

CDS 140	18 units
Additional Advanced Courses in CDS	36 units
Engineering Electives (focus area)	27 units
General Electives	36 units

The 36 units of general electives should include mathematics, science and engineering subjects or research, but may be, with special permission, humanities and social sciences.

All M.S. students are required to submit candidacy forms to the Institute for approval of the proposed course of study for the M.S. degree. The M.S. candidacy form must be submitted by midterm (approximately mid-November) of the first term of the year when the degree is expected. These forms can be obtained at the Institute Graduate Office.

8 CDS Seminars

Graduate Students are expected to attend all regular CDS seminars. The opportunity to learn about the research of those at other institutions is an important part of a graduate education, even if that research is not in your own specific dissertation area. From time to time, we schedule seminars, announced on relatively short notice when the speaker is passing through the area, that are designated as Special CDS Seminars. Although wide attendance at these special seminars is, of course, desired, we recognize that these may be of interest to only a limited number of students and do not necessitate the full attendance that we require at our regular seminars. Notices of seminars are posted via e-mail.

9 Vacation Policy

Graduate students are entitled vacation on all Institute staff holidays as listed in the Institute Catalog. In addition, the Institute allows at least two weeks vacation. The CDS faculty believes that the allowance of two weeks of vacation, in addition to Institute holidays, is adequate. We regard a request for more than two weeks of vacation per year as a special request, which your advisor may grant without compensation or, at his or her discretion, with compensation. It is a matter of the personal integrity of all the students and the faculty to ensure that the flexibility in the Option policy is not abused. In all cases, vacation should be scheduled in consultation with your research advisor.