This project summarizes the main concerns of this course: automata, languages, and functions as models of computation; expressiveness of these models; and limitations of them.

The work is also part of the capstone experience for the CS-General concentration of the Computer Science major. Thus its goal is to help you sum up your understanding of computer science. The CSCI 460 project addresses mainly the theoretical side of the discipline. The other part of the capstone experience is the Operating Systems Internals project (CSCI 465), which helps summarize a practical understanding of programming and operating systems.

For the project, each student is to gather his/her answers to certain out-of-class exercise problems (corrected and expanded), together with definition, coding, and research components. Within the project specs, you will make a number of choices, including the ordering of material and the selection of problems. For example, you may wish to organize the project by the project components listed in subheadings below, or by class of model of computation.

The end result is to be well formatted and in a binder and stored in an online department repository of student work, which students may make available to anyone they choose, such as hiring departments in job searches. The work will be done in three stages, each time with student presentation and feedback.

### Definition component

Define and describe, in your own words, one model of computation from each class below:

- **bounded-input** (logic circuit, branching transition system, lookup table, predicate logic)
- **finite-state** (DFA, NFA, finite transducer, regular-expression language)
- **stack** (PDA, context-free grammar)
- **algorithmically complete** (TM, random access machine, μ–recursive functions, lambda calculus)
- **interactive** (Persistent Turing machine, Markov model, Kripke structure, interactive finite-state machine, Reo channel, Pi calculus, cellular automata, neural net)

Illustrate at least one of the models you choose with a diagram.

### Proof component

Begin with the assigned problems involving proofs of expressiveness in out-of-class exercises 1-6. Each student is to present and explain theoretical results about the computing power of one model under each topic. Each project is thus unique, using different examples and proving different results.

You are welcome to look at the work of other students in order to understand concepts, but not to copy words. If you use others’ ideas, then acknowledge your sources.

Show at least one result (proof) about the limitations of the expressiveness of a model.

The outcome of this part of the project will be a unique, selected but wide-ranging story told by each student about the increasingly powerful models of computation that we are studying.

### Coding component

In out-of-class exercises 2 and 3, students cooperatively implement lexical analyzers and parsers for small subsets of Java. Include in the project an explanation of the code that you wrote for this group work and explanation of test results. Append to your project this code, with full documentation and test results.

An alternative is to write or modify code related to some other aspect of the course. Code is available on automata, random-access-machine, and parallel and distributed computing simulators.

Some students will choose to make the coding a large part of the project.
**Research component**

The research component is to be of at least 300 words, on a topic, in some area covered by the course, proposed by the student and approved by the instructor. Two or more sources should be from edited journals, peer-reviewed conference proceedings, or academic books such as textbooks.

Include references within the text of your paper and a bibliography at the end in standard bibliographic format, including author name and publication information.

The research may be placed anywhere in the project, separately or embedded in sections of the project.

**Personal statement component**

Include your own reflections about the practical or broader implications of your studies in Theory of Computing. Have your ideas about computation and its possibilities and limits changed?

Does the course material, as you see it, relate to robotics, biology, software engineering, or the modeling of natural or human behavior? Include any thoughts or research discoveries that are new to you or that you think are relevant.

You are invited to illustrate your paper or to attach video clips.

**Initial submission (due in first month)**

Include:
- *Title*: of more than one word; like anything else in your proposal, you may change this later;
- *Initial abstract*: a paragraph or so about the topic, including some factual assertion about the topic and a statement of what you hope to learn;
- *References*: short initial list of 2-3 sources in standard bibliographic format.

**Preliminary draft (due in middle of course)**

Please write at least 600 words, including at least three proofs in your own words; a half page or more of research results, and a half page or more of personal reflection. Please respond to my comments on your proposal.

Plan to talk about this preliminary draft in class. Post your draft or share with another student for a peer review (see sheet, “Student peer review”).

**Final draft (due in last third of course)**

Final draft (at least 1500 words) is to respond to instructor comments and other students’ comments about your preliminary draft.

**Assessment criteria**

- Three submissions
- Five components
- Final written presentation
- Oral presentation
- Use of sources
Introductory out-of-class exercise

A. Background and self introduction
At the Discussion Board, Forum “Introduction,”
(a) Please comment in some way on your background or expectations for the course.
(b) State what most stayed in your mind in discussing this topic, and if you wish, the least clear concept that you encountered in this topic.

B. Collaborative exercise
Submit results of classroom exercise (slide 3) answering one of the following questions:
1. Describe one or two models of computation
2. What is computing power?
3. What use is theory for a software engineer?
Include the names of those who participated in the group
Topic 1 out-of-class exercise (Sets, languages, models)

I. Response to classroom discussion or reading
In at least two sentences, please identify one or more of the following, based on your reading, the slides, or the class discussion about this topic:
   a. an idea that you see now in a new way before;
   b. a concept or slide that is not clear to you.

II. Objectives-related exercises
For as many of the objectives below as you can, solve the problem corresponding to your classroom ID. In most cases, refer to the Topic 1 Study Questions, Longer Answer. You may wish to start with and to focus on the objectives marked “core”. Please submit on paper, giving your name, the topic number, and the problem letter and number, and restating the problem. You are invited to post at the Discussion Board as well.

1a. Formal language notation (core)
See study questions.

1b. Expressiveness of logic circuit model (core)
See study questions.

1c. Prove a set countable
See study questions.

1d. Diagonal proof
See study questions.

1e. Coinduction
See study questions.

III. Written collaboration
Respond meaningfully on the Discussion Board to another student’s posted solution to one of the above problems.

IV. Group activity
With your group, prepare a presentation of a solution to one of the problems among part II above. Assign one member of your group to present the solution in class. This presentation may describe an effort to solve the problem and may request help in this effort. On paper, submit the names of those who participated in the group and describe the group process, including the division of labor among group members.

V. Extra-credit exercises

Short-answer
See second page of Study Questions; answer one or more, starting with a question whose number is your classroom ID.

Coding exercise
Write a Java program to compute the value of the sentence, in the list of propositional logic sentences at Study Questions, Topic 1, “Propositional-logic sentences” corresponding to your classroom ID. The Java program should input four truth values (e.g., 0 or 1) and should output a truth value.
Topic 2 out-of-class exercise (DFAs and RLs)

I. Response to classroom discussion or reading
In at least two sentences, please identify one or more of the following, based on your reading, the slides, or the class discussion about this topic:

a. an idea that you see now in a new way before;

b. a concept or slide that is not clear to you.

II. Objectives-related exercises
For as many of the objectives below as you can, solve the problem corresponding to your classroom ID. In most cases, refer to the Topic 2 Study Questions, Longer Answer. You may wish to start with and to focus on the objectives marked “core”. Please submit on paper, giving your name, the topic number, and the problem letter and number, and restating the problem. You are invited to post at the Discussion Board as well.

2a. DFA construction (core)
See study questions.

2b. Proof of correctness of DFA (core)
Prove by structural induction that your answer in part B is correct.

2c. Regular expressions (core)
Write a regular expression for the language assigned for part B above, using DIGIT if necessary for {0 .. 9}.

2d. Expressiveness (core)
See study questions.

2e. Pumping Lemma problems
See study questions.

III. Written collaboration
Respond meaningfully on the Discussion Board to another student’s posted solution to one of the above problems.

IV. Group activity
With your group, prepare a presentation of a solution to one of the problems among part II above. Assign one member of your group to present the solution in class. This presentation may describe an effort to solve the problem and may request help in this effort. On paper, submit the names of those who participated in the group and describe the group process, including the division of labor.

V. Extra-credit exercises
NFA construction
See Study Questions, “Miscellaneous,” NFA construction problems. Describe the process for deriving the corresponding DFA by subset construction.

Structural induction
See the section, “Structural Induction,” in the Study Questions. Solve a problem there.

Coding exercise
Write a lexical analyzer for one of the following Java expressions. (a) logical; (b) arithmetic; (c) relational.

All versions should include numeric literals, variable names, and the appropriate operators.

Output should be a linked list of objects, each of which contains the text of the lexeme and its lexical category. Document your code to reflect how it implements a DFA.

Suggested approach:
- The DFA’s state can be represented by an integer variable. The state transition function is represented by a switch statement that assigns a new state value to the state variable depending on what the most recent input character is.
- The easiest way to develop and test is to read text files and display a “yes” or “no” result.
- In one of the states, a token has just been recognized. Make sure that when your DFA is in this state, a method is called that adds an object to your linked list of token objects.
Topic 3 out-of-class exercise (PDAs and CFLs)

I. Response to classroom discussion or reading
In at least two sentences, please identify one or more of the following, based on your reading, the slides, or the class discussion about this topic:

a. an idea that you see now in a new way before;
b. a concept or slide that is not clear to you.

II. Objectives-related exercises
For as many of the objectives below as you can, solve the problem corresponding to your classroom ID. In most cases, refer to the Topic 3 Study Questions, Longer Answer. You may wish to start with and to focus on the objectives marked “core”. Please submit on paper, giving your name, the topic number, and the problem letter and number, and restating the problem. You are invited to post at the Discussion Board as well.

3a. PDA model (core)
Solve the problem in Study Questions, Topic 3, “3a. PDA model.”

3b. Context-free grammar
Solve a problem in “3b. CFG.”

3c. Derivation
Solve a problem in “3c. Derivation.”

3d. Proof of expressiveness (core)
Solve a problem in “3d. Proof of expressiveness.”

III. Written collaboration
Respond meaningfully on the Discussion Board to another student’s posted solution to one of the above problems.

IV. Group activity
With your group, prepare a presentation of a solution to one of the problems among part II above. Assign one member of your group to present the solution in class. This presentation may describe an effort to solve the problem and may request help in this effort. On paper, submit the names of those who participated in the group and describe the group process, including the division of labor among group members.

V. Extra-credit exercises

Linear CFG
Explaining your method, define a right-linear CF grammar for

1. \((0 \mid 10)^*\)
2. \((1^* (01)^*)\)
3. \((1^* 0\)
4. \((11 \mid 10)^*\)
5. \((0^* (10)^*\)
6. \((00 \mid 11)^*\)

Parser problem
Write a top-down parser that accepts the language generated by the part of the CF grammar defined below, where words such as “expr” are either nonterminals or lexical categories for which you wrote a lexer in exercises for topic 2.

\[ S \rightarrow \text{identifier assign-op expr semi-colon} \]
\[ \text{expr} \rightarrow \text{arith-expr arith-op arith-expr} \]
\[ \text{expr} \rightarrow \text{log-expr log-op log-expr} \]
\[ \text{expr} \rightarrow \text{rel-expr rel-op rel-expr} \]

Limitations of PDA model
Show a language that is not context-free, explaining why it is not CF.

Coding exercise
Write a parser of a subset of Java (e.g., numeric or logical expressions) as part of a group project.
Topic 4 out-of-class exercise (Turing machines)

I. Response to classroom discussion or reading

In at least two sentences, please identify one or more of the following, based on your reading, the slides, or the class discussion about this topic:

a. an idea that you see now in a new way before;
b. a concept or slide that is not clear to you.

II. Objectives-related exercises

For as many of the objectives below as you can, solve the problem corresponding to your classroom ID. In most cases, refer to the Topic 4 Study Questions, Longer Answer. You may wish to start with and to focus on the objectives marked “core”. Please submit on paper, giving your name, the topic number, and the problem letter and number, and restating the problem. You are invited to post at the Discussion Board as well.

4a. Describe TM model (core)

Solve the problem corresponding to your classroom ID in Study Questions, Topic 4, “4a. Describe TM model.”

4b. Decidability (core)

Solve the problem corresponding to your classroom ID in Study Questions, Topic 4, “4b. Decidability.”

4c. Undecidability (core)

Solve the problem corresponding to your classroom ID in Study Questions, Topic 4, “4c. Undecidability.”

4d. Reducibility

Solve the problem corresponding to your classroom ID in Study Questions, Topic 4, “4d. Reducibility.”

5c. Expressiveness

Give a proof of the expressiveness of Turing machines, i.e., a class of problems solvable or a class of languages decidable by TMs.

1. Explain why any language recognized by a DFA must also be recognized by some TM.
2. Explain how we know all CFLs are decidable.
3. Explain how we know all regular languages are decidable.
4. Show that Turing machines accept a strict superset of the CFLs.
5. Compare the expressiveness of Turing machines and {DFAs, NFAs, PDAs, regular expressions, CF grammars}. Justify your answer rigorously.
6. Refute the following: “Turing machines have no more computational power than finite lookup tables in which inputs and outputs are listed, and in which to find \( f(x) \) one just looks up the table entry with \( x \) in the left column. A TM may actually be represented as a lookup table: origin state, symbol fetched, destination state, symbol to write, left or right move.

III. Written collaboration

Respond meaningfully on the Discussion Board to another student’s posted solution to one of the above problems.

IV. Group activity

With your group, prepare a presentation of a solution to one of the problems among part II B-F above. Assign one member of your group to present the solution in class. This presentation may describe an effort to solve the problem and may request help in this effort. On paper, submit the names of those who participated in the group and describe the group process, including the division of labor among group members.
I. Response to classroom discussion or reading
In at least two sentences, please identify one or more of the following, based on your reading, the slides, or the class discussion about this topic:
   a. an idea that you see now in a new way before;
   b. a concept or slide that is not clear to you.

II. Objectives-related exercises
For as many of the objectives below as you can, solve the problem corresponding to your classroom ID. In most cases, refer to the Topic 5 Study Questions, Longer Answer. You may wish to start with and to focus on the objectives marked “core”.
Please submit on paper, giving your name, the topic number, and the problem letter and number, and restating the problem. You are invited to post at the Discussion Board as well.

5a. Random-access machine model (core)
In Study Questions, topic 5, answer a question under objective 5a whose number corresponds to your classroom ID.

5b. Recursive definability and computability (core)
See Study questions, topic 5, “Objectives-related questions.” Answer the question, under objective 5b, whose number corresponds to your classroom ID.

5c. Expressiveness of the RAM model (core)
Answer the question under objective 5c whose number corresponds to your classroom ID.

5d. Chomsky hierarchy (core)
Answer the question under objective 5d whose number corresponds to your classroom ID.

5e. Semi-decidability
Answer the question under objective 5e whose number corresponds to your classroom ID.

III. Written collaboration
Respond meaningfully on the Discussion Board to another student’s posted solution to one of the above problems.

IV. Group activity
With your group, prepare a presentation of a solution to one of the problems among part II above. Assign one member of your group to present the solution in class. This presentation may describe an effort to solve the problem and may request help in this effort. On paper, submit the names of those who participated in the group and describe the group process, including the division of labor among group members.

V. Extra-credit exercises
Programs in the \( \mathcal{F} \) language
See Study Questions.
Topic 6 out-of-class exercise (Interaction)

I. Response to classroom discussion or reading
In at least two sentences, please identify one or more of the following, based on your reading, the slides, or the class discussion about this topic:

a. an idea that you see now in a new way before;

b. a concept or slide that is not clear to you.

II. Objectives-related exercises
For as many of the objectives below as you can, solve the problem corresponding to your classroom ID. In most cases, refer to the Topic 6 Study Questions, Longer Answer. You may wish to start with and to focus on the objectives marked “core”.

Please submit on paper, giving your name, the topic number, and the problem letter and number, and restating the problem. You are invited to post at the Discussion Board as well.

6a. Algorithmic and interactive computation (core)
See Study questions, topic 6, “Objectives-related questions.” Answer the question under 6a that corresponds to your classroom ID.

6b. Model of sequential interaction (core)
See Study questions, topic 6, “Objectives-related questions.” Answer the question under 6b that corresponds to your classroom ID.

6c. Expressiveness
See Study questions, topic 6, “Objectives-related questions.” Answer the question under 6c that corresponds to your classroom ID.

6d. Define PTM
See Study questions, topic 6, “Objectives-related questions.” Answer the question under 6d that corresponds to your classroom ID.

III. Written collaboration
Respond meaningfully on the Discussion Board to another student’s posted solution to one of the above problems.

IV. Group activity
With your group, prepare a presentation of a solution to one of the problems among part II above. Assign one member of your group to present the solution in class. This presentation may describe an effort to solve the problem and may request help in this effort. On paper, submit the names of those who participated in the group and describe the group process, including the division of labor among group members.
Topic 7 out-of-class exercise (Concurrency)

I. Response to classroom discussion or reading
In at least two sentences, please identify one or more of the following, based on your reading, the slides, or the class discussion about this topic:

a. an idea that you see now in a new way before;
b. a concept or slide that is not clear to you.

II. Objectives-related exercises

For as many of the objectives below as you can, solve the problem corresponding to your classroom ID. In most cases, refer to the Topic 7 Study Questions, Longer Answer. You may wish to start with and to focus on the objectives marked “core”. Please submit on paper, giving your name, the topic number, and the problem letter and number, and restating the problem. You are invited to post at the Discussion Board as well.

7a. Forms of concurrency (core)
See Study questions, topic 7, “Objectives-related questions.” Answer a question under 7a that corresponds to your classroom ID.

7b. Parallel models (core)
See Study questions, topic 7, “Objectives-related questions.” Answer the question under 7b that corresponds to your classroom ID.

7c. Connectionist and multi-agent models (core)
See Study questions, topic 7, “Objectives-related questions.” Answer the question under 7c that corresponds to your classroom ID.

7d. Expressiveness of parallel models
See Study questions, topic 7, “Objectives-related questions.” Answer the question under 7d that corresponds to your classroom ID.

7e. Expressiveness of multi-stream interaction
See Study questions, topic 7, “Objectives-related questions.” Answer the question under 7e that corresponds to your classroom ID.

III. Written collaboration

Respond meaningfully on the Discussion Board to another student’s posted solution to one of the above problems.

IV. Group activity

With your group, prepare a presentation of a solution to one of the problems among part II above. Assign one member of your group to present the solution in class. This presentation may describe an effort to solve the problem and may request help in this effort. On paper, submit the names of those who participated in the group and describe the group process, including the division of labor among group members.