This document describes what students are expected to submit for the programming assignments, and how their submissions will be evaluated. A handout is provided for each programming assignment that describes the motivation for the assignment and provides background on the required implementations, testing strategy, and evaluation. Each programming assignment requires you to submit three parts: the PA milestone (i.e., one or more initial implementations along with the corresponding tests); the PA code (i.e., all implementations along with all tests); and the PA report (i.e., a three page document including an introduction, deep dive discussion of one or more implementations, and evaluation). Students must also submit a two-page testing strategy report that makes a compelling argument for the correctness of their first three PAs. Although each of these parts is graded separately, it is also useful to consider their relative importance to your final grade. The PA code is worth 25% of your final grade; the PA reports are worth 10% of your final grade; and the PA milestones are worth 5% of your final grade. In total, the PAs are worth 40% of your final grade.

Any programmer can write code. Good programmers can write code for multiple implementations, use a testing strategy to verify these implementations are correct, and evaluate the performance and space usage of these implementations. Great programmers can do all of these things, but can also explain their how their implementations work at a high level, justify the specific design choices used in their implementations, use an evidence-based approach to make a compelling argument that their code is correct, and both qualitatively and quantitatively compare and contrast different implementations. Doing well on the PA milestones and code means you are making progress towards being a good programmer. Doing well on the PA milestones, code, and reports means you are making progress towards being a great programmer. By the end of the semester, we hope every student will have evolved from simply being a programmer to being a great programmer.

1. PA Code Release

Initial code for each PA will be released through GitHub, and students will be using GitHub for all development related to the PA. Every student will have his or her own private repository for the first three PAs. Each group of two students will have their own group repository for the last two PAs. All of these repositories will be part of the cornell-ece2400 GitHub organization, and all development must be done in these specific repositories. You should never fork your remote repository! If you need to work in isolation then use a branch within your remote repository. The course instructors will merge new code into the each of these remote repositories, and then students simply need to pull these updates.

2. PA Code Submission

The PA milestone and the final code will be submitted via GitHub. If you are trying to submit your code at the last minute, then it is possible these last minute changes may not make it into your
finalized submission. You should make sure your final code is pushed to GitHub well before the deadline.

You should browse the source on GitHub to confirm that the code in the remote repository is indeed the correct version. Make sure all new source files are added, committed, and pushed to GitHub.

You should not commit the build directory or any generated content (e.g., object files, executable binaries, unit test outputs). Including generated content in your submission will impact the grade for the PA milestone and code.

For the PA milestones, you should confirm that a clean clone of your PA correctly builds and passes all of the tests you expect to pass using the following process:

```bash
% mkdir -p ${HOME}/ece2400/submissions
% cd ${HOME}/ece2400/submissions
% rm -rf repo
% git clone git@github.com:cornell-ece2400/repo

% cd ${HOME}/ece2400/submissions/repo/pa-name
% mkdir -p build
% cd build
% cmake ..
% make check-milestone
```

where repo is either your NetID for the first three PAs or your group repo for the final two PAs, and pa-name is the name of the PA (e.g., pa1-math for the first assignment). Some PAs may also require students to pass memcheck-milestone.

For the final PA code submission, you should confirm that a clean clone of your PA correctly builds, passes all of the tests you expect to pass, and also completes the evaluation using the following process:

```bash
% mkdir -p ${HOME}/ece2400/submissions
% cd ${HOME}/ece2400/submissions
% rm -rf repo
% git clone git@github.com:cornell-ece2400/repo

% cd ${HOME}/ece2400/submissions/repo/pa-name
% mkdir -p build
% cd build
% cmake ..
% make check

% cd ${HOME}/ece2400/submissions/repo/pa-name
% mkdir -p build-eval
% cd build-eval
% cmake -DCMAKE_BUILD_TYPE=eval ..
% make eval
# ... run the eval programs ...
```

Some PAs may also require students to pass memcheck. If, for any reasons, the above steps do not work, then the score for code functionality will be reduced. For example, students occasionally forget
to commit new source files they have created in which case these new files will not be in the remote repository on GitHub.

We will be using TravisCI to grade the code functionality for the PAs. So in addition to verifying that a clean clone works on the ecelinux machines, you should also verify that all of the tests you expect to pass are passing on TravisCI by visiting the TravisCI page for your repository:

- https://travis-ci.com/cornell-ece2400/repo

where repo is either your NetID for the first three programming assignments or your group repo for the final two PAs. If your code is failing tests on TravisCI, then the score for code functionality will be reduced. Keep in mind that in the final few hours before the deadline, the TravisCI work queue can easily fill up. You should always make sure your tests are passing on the ecelinux machines and not rely solely on TravisCI to verify which tests are passing and failing.

3. PA Code Revision

After the deadline for submitting the final code, the course instructors will branch your submission and create a pull request on GitHub. The instructors will then commit the instructor tests and evaluation program into this pull request which will trigger a TravisCI build. This will enable the instructors and the students to immediately see how their submission does on both the student tests and the instructor tests. If the student’s PA fails some of the instructor tests, then the students are free to fix bugs and commit these changes as part of the pull request. The students are encouraged to add comments to the pull request indicating what they had to change to pass the instructor tests, and why the student tests did not catch this bug. This code revision will not mitigate a reduction in the code functionality score due to failing instructor tests, but it will enable the course staff to judge how severe a penalty to access. If it turns out that after the students fix a very small mistake in their code, their programming assignment now passes all of the tests then this will result in a small penalty. If it turns out that the students have to fix a major mistake, then this will result in a larger penalty, but at least the students will have figured out what is wrong. Such code revisions will need to be made within a few days of the deadline.

4. PA Report Submission

In addition to the actual code, we also require students to submit a PA report. The report offers an opportunity for students to convey the high-level implementation approach, motivation for specific design decisions, qualitative comparison of various trade-offs, and qualitative evaluation of performance and space usage trade-offs. We would argue that the ability to convey this information via a technical report is just as important, or potentially even more important, than simply writing code.

The PA report should be written assuming the reader is familiar with the lecture material and has read the PA handout. You might need to paraphrase some of the content in the handout in your own words to demonstrate understanding. Details about the actual code should be in the code comments. The report should focus on the high-level implementation and evaluation aspects of the assignment. All reports should include a title and the name(s) and NetID(s) of the student(s) which worked on the assignment at the top of the first page. Do not put this information on a separate title page. The report should be written using a serif font (e.g., Times, Palatino), be single spaced, use margins in the range of 0.5–1 in, and use a 10 pt font size. All figures must be legible. Avoid scanning hand-written figures and do not use a digital camera to capture a hand-written figure. Do not just use a screen capture of code. Definitely do not include screen captures that have white text on a black background. This is not an appropriate way to include code in a technical document. Cut and paste the code into
your report and format it appropriately. Clearly mark each section with a numbered section header. Your report should not look like an outline. It should look like a report with paragraphs and prose. Avoid subsections unless there is a very compelling reason to include them. You should include the following sections:

- **Section 1. Introduction (1 paragraph maximum)** – Students must summarize the purpose of the PA. Why are we doing this assignment? How does it connect to the lecture material? There are often many purposes. Think critically about how the assignments fits into the other PAs. Students can paraphrase from the handout as necessary. Students must include a sentence or two that describes at a very high-level their implementations. The introduction should be brief but still provide a good summary of the PA.

- **Section 2. Implementation Deep Dive** – The PA handout will indicate one implementation that the students should focus on in their implementation deep dive. Students do not need to discuss the other implementations; only the implementation explicitly mentioned in the PA handout. Think critically about what are the key items to mention in order for the reader to understand how the implementation works. You will likely need to summarize some information from the handout in your own words. Examples are usually great to include here to illustrate how the implementation works. Students are highly encouraged to include pseudocode where appropriate. Do not include C code; your report should be at a higher level. Students should explain why this implementation is interesting to study in the context of the PA. For PA4 and PA5, students should discuss in detail what optimizations they used for this implementation. Students must provide a balanced discussion of not just the implementation itself, but why you chose to take this approach.

- **Section 3. Qualitative Comparison** – Students must qualitatively compare and contrast the all implementations and demonstrate understanding of various implementation trade-offs. Students must discuss the modularity (How is the interface separated from the implementation? Is this a good interface?), implementation complexity (Which design is simpler? Why?), and extensibility (Which design will be easier to maintain or modify in the future?) of each implementation. Students should make a qualitative judgment on the implementation’s performance and space usage. After students have learned about complexity analysis, they should incorporate this kind of analysis into this section. For PA4 and PA5, students should briefly mention what optimizations they used across all implementations.

- **Section 4. Quantitative Evaluation** – Students should revisit their qualitative evaluation from the previous section using quantitative data in this section. Students must report their performance results using a table and/or plot as appropriate. Do not simply include the text output from running the evaluation programs. Format the data so it is appropriate for a report. You must explain how you collected this data (number of subtrials? number of trials? what was the variance?). You must include some kind of analysis of the results: Why is one implementation better or worse than another? For PA4 and PA5 students will likely need to quantitatively evaluate various optimizations. Remember to provide a balanced discussion between what the results are and what those results mean.

- **Section 5. Conclusion (1 paragraph maximum)** – Students must include a brief qualitative and quantitative overview of the evaluation results (Which implementation performed best? By how much? On which inputs?). Students must include some high-level conclusions they can draw from their qualitative and quantitative evaluation. Do not over-generalize. Can you predict how the results might change for other inputs? What can we learn from these results? Which implementation should we use in the future? If it depends, explain why it depends.
It is also always great to include extra material to help demonstrate your understanding. You could include an example of a state diagram like we do in lecture for a small example. You could implement another implementation to gather additional data points to make for a richer comparative analysis in the quantitative evaluation section. You could try more evaluation inputs to illustrate a point. Be sure to highlight "extra" work you did in your implementation or evaluation sections. There are many creative things you can do to set your report apart!

Sections 1–5 (including the title and author list) can be a maximum of three pages. These sections must fit within the first three pages of your report. We do not recommend including pseudo-code, diagrams, plots, and tables in these three pages since this means you will have less room for text (and puts pressure on making the diagrams, plots, and tables too small). Instead, you can have an appendix at the end of your report which includes all pseudo-code, diagrams, plots, and tables. Be sure to number pseudo-code, diagrams, plots, and tables and reference them throughout your discussion. The appendix can be a maximum of three pages. This means the entire report must be less than six pages.

Many students initially struggle with the idea of preparing the PA report. In previous courses, students often simply describe their code at a low level in a PA report. In this course, we are challenging students to prepare reports that better demonstrate the student’s understanding of the course content. Before starting to write the report, we encourage students to prepare a detailed outline. The outline should include one section for each of the five sections that will eventually make up the report. Under each section, there should be one bullet for each paragraph the student is planning to include in that section. This bullet should describe the topic of the paragraph. Under each bullet there should be several sub-bullets, one for each topic to be discussed in that paragraph. The outline should also explicitly include references to the figures, tables, and plots the student plans to include in the report. This is called a structured approach to technical writing. Students are strongly discouraged from “just starting to write”. Just like we should always plan our approach before starting to write our programs, we should plan our approach before writing the report. Students are encouraged to review their outline with the course staff several days before the deadline.

To help students understand our expectations, we have prepared a rough outline for a report for the first PA. It is available on the Canvas course site. Here is a direct link:

- http://www.csl.cornell.edu/courses/ece2400/handouts/ece2400-pa1-math-outline.txt

Students do not need to follow this outline, nor should students expect a similar outline for future PAs. Keep in mind that any outline will evolve as you start writing the report. This outline is simply meant as an example to demonstrate our expectations and our suggested approach for writing great reports; which ultimately will enable students to become great programmers.

Your report should be uploaded to Canvas. We use when the PA report is uploaded to Canvas to track how many slip days students want to use.

5. PA Testing Strategy Report Submission

Students are required to submit a 2–3 page testing strategy report near the middle of the semester. This report is meant to holistically reflect the student’s understanding of how to to create an effective testing strategy for computer systems programs based on their experiences in the first three PAs. Your report should include the following numbered sections:

- **Section 1. Introduction (1 paragraph maximum)** – Students must clearly indicate why we need to develop a testing strategy. Briefly list the six testing techniques (i.e., ad-hoc testing, black-box directed testing, white-box directed testing, black-box random testing, memcheck...
testing, coverage-based testing). Briefly mention applying the five techniques to the first three PAs.

- **Section 2. Testing Techniques** – For each of the five testing techniques (i.e., ad-hoc testing, black-box directed testing, white-box directed testing, black-box random testing, memcheck testing, coverage-based testing) discuss: What is that testing technique? Why we should use that testing technique? What is the actual concrete way we implement and use that technique in the programming assignments? Focus on the general mechanism, since you will discuss specifically applying to the three PAs in the next section.

- **Section 3. Applying Testing Techniques** – For each of the three PAs discuss: How did you apply the five testing techniques to that PA? What was the number of directed and random test cases for that PA? What was your coverage metric for that PA? If code coverage was less than 10)% explain why? Is this okay? Any interesting corner cases caught by your testing strategy? If you passed your tests but failed one or more staff tests, please explain why? What was missing in your testing strategy? How could you have improved your testing strategy to catch this bug earlier? Be specific about how you applied directed and random testing! Be specific about white-box vs black-box testing!

- **Section 5. Conclusion (1 paragraph maximum)** – Briefly list the four testing techniques (i.e., ad-hoc testing, black-box directed testing, white-box directed testing, black-box random testing, memcheck testing, coverage-based testing). Briefly mention applying the five techniques to the first three PAs. Pull together your complete testing strategy to make a compelling argument for the correctness of the code in your first three PAs.

As with the PA reports, students must balance discussing the *what* with the *why*. Just saying you used a specific testing technique is not sufficient. Be specific and explain *why* you used a specific testing technique (e.g., why use directed testing? why use random testing?). Do not include the actual test code itself; your report should be at a higher level. Do not include the output from running the tests (we can see that on TravisCI). To help students understand our expectations, we have prepared a rough outline for the testing strategy document. It is available on the Canvs course page. Here is a direct link:

- [http://www.csl.cornell.edu/courses/ece2400/handouts/ece2400-testing-outline.txt](http://www.csl.cornell.edu/courses/ece2400/handouts/ece2400-testing-outline.txt)

6. **PA Assessment Rubric**

The PA milestones are assessed holistically on whether or not both implementations are working and how much effort has been put into the initial testing strategy.

The PA code is assessed using three criteria weighted as follows:

- **Code Functionality** 60%
- **Verification/Optimization Quality** 30%
- **Code Quality** 10%

As discussed in the syllabus, each criteria/subcriteria is scored on a scale from 0 (nothing) to 4.25 (exceptional work). The functionality of the implementations is assessed based on the number of test cases that pass in both the student and instructor test suites in combination with the severity of any errors. The verification quality is assessed for PA1–3 based on the judgment of the instructor in terms of how well the students’ test cases actually test the design. The optimization quality is assessed for PA4–5 based on holistic quantitative analysis of the performance and accuracy of all
implementations. The code quality is based on: how well the code follows the course coding guidelines; inclusion of comments that clearly document the structure, interfaces, and implementation; following the naming conventions; decomposing complicated monolithic expressions into smaller sub-expressions to increase readability. Overall, good code quality means little work is necessary to figure out how the code works and how we might improve or maintain the design.

The PA report is assessed using the following criteria:

- Introduction/Conclusion 20%
- Implementation Deep Dive 20%
- Qualitative Comparison 20%
- Quantitative Evaluation 20%
- Writing Quality 10%

Again, each criteria/subcriteria is scored on a scale from 0 (nothing) to 4.25 (exceptional work). A detailed rubric will be provided with the final PA report grade to explain how each section was assessed.

7. GitHub and Academic Integrity Violations

Students are explicitly prohibited from sharing their code with anyone that is not within their group or on the course staff. This includes making public forks or duplicating this repository on a different repository hosting service. Students are also explicitly prohibited from manipulating the Git history or changing any of the tags that are created by the course staff. The course staff maintain a copy of all repositories, so we will easily discover if a student manipulates a repository in some inappropriate way. Normal users will never have an issue, but advanced users have been warned.

Sharing code, manipulating the Git history, or changing staff tags will be considered a violation of the Code of Academic Integrity. A primary hearing will be held, and if found guilty, students will face a serious penalty on their grade for this course. More information about the Code of Academic Integrity can be found here:

- http://theuniversityfaculty.cornell.edu/academic-integrity