Summer Research Program in Industrial and Applied Mathematics

SEOUL NATIONAL UNIVERSITY

Sponsor

⟨**Tencent**⟩

Final Report

⟨Sketch to Image Generation⟩

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Abstract

In this project, we investigated sketch-to-image translation by implementing Cycle-GAN to learn the mapping between human face sketch to realistic photograph. We used U-net to form the Generative Adversarial Networks This makes the model possible to train end to end from very few images and guaranteeing the performance of the mapping.

Acknowledgments

It is appropriate in the Acknowledgments to thank individuals or organizations who made especially noteworthy contributions to your project. Elsewhere, within the body of the report, you can acknowledge more specific contributions where appropriate. These are matters of courtesy and professional ethics. As an example:

> The RIPS LaTeX report template has been developed by Mike Raugh with advice and assistance from Oleg Alexandrov and Shawn Cokus in the early stage of development and general support of IPAM and the System Administration staff. The first RIPS template was based on an early version of the Math Clinic's report template at Harvey Mudd College; there the original template has been improved and is managed by Claire Connelly, the HMC Math Department's system administrator. Claire and her co-authors offer coding advice, a wealth of references, and a note about the origin of the template in their current edition, the `sample-clinic-report.pdf` accessible at `http://www.math.hmc.edu/computing/support/tex/sample-report`. Claire copyedited the third edition of Grätzer's *Math into LaTeX*, most of which work seems to have survived into the fourth edition: *More Math into LaTeX* [**?**].

When acknowledging individuals in this section, it is OK to use the names by which you know and speak to them. Here it is OK to write "Oleg Alexandrov." But you must be formal on the Title page and elsewhere within the report, where it is proper to specify honorifics, e.g., Dr. or Prof. On the Title page you would write "Dr. Oleg Alexandrov," and likewise within the body of the report if you were acknowledging him for a specific contribution, Claire Connelly uses no honorific, so you would use just her name on the title page. When in doubt, check the person's business card or follow usage on the person's web page.

As a result of suggestions from users, this Sample Report and its source are under continual improvement. Please contact the RIPS program director for your suggestions. An up-to-date list of changes is recorded in the "Revisions" folder for the Master Template Folder.

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Chapter 1

Introduction

1.1 Project Goal

The goal of this project is to build a system that can generate photo-realistic images from rough sketch pictures. For that, we utilized the Cycle-GAN [13]

1.2 Related Works

Sketch-to-Photograph generation is a sub-problem of Image-to-Image translation where the goal is to learn the mapping between distinct domains of image.

In 2017, Jun-Yan Zhu et al. achieved transforming a horse image into a zebra using Cycle-Consistent Adversarial Networks. However, in the Sketch-to-Image generation, the mapping between photo and sketch always cause loss in dimension of data, resulting in losting the uniqueness of mapping. Our goal is to train a Cycle-Consistent Adversarial Networks to learn a mapping $G : X \rightarrow Y$ such that the distribution of images from $G(X)$ indistinguishable from the distribution Y. In other word, it can generate high quality human face photograph from face sketch image.

GAN: A method of handling Image translation problem is to adopt a Generative adversarial network. Implementing adversarial loss, GAN is able to train the convergence algorithm so that the generator's distribution converges to the data[3] . This contributed to the success of GAN in generating realistic images with an impressive result.

Pix2Pix: The framework of Pix2Pix is based on GAN. With a paired training example, Pix2Pix is able to deal with Image-to-Image translation

CycleGAN: As an improvement of Pix2Pix, the model of CycleGAN does not required paired training examples to train the model. It contains two mapping functions $G : X \rightarrow Y$ and $F : Y \rightarrow X$ from two data sets X, Y, and associated with two discriminators D_X and D_Y. In the model, two cycle consistency losses (Forward and Backward) was introduced so that it can achieve two mapping where $F(G(x)) \approx x$ and $G(F(y)) \approx y$[13]. In this work, we implemented the CycleGAN to work on the Sketch-to-Image translation. Using the U-net instead of the ResNet, we trained the model to specialized in generating realistic human face photograph from a human face sketch as well as generating sketch from human face photograph such that both

sketches and human face photograph are indistinguishable from target domain.

The team would like to thank *Tencent* for the generous sponsorship of this project.

Our code is available at `https://github.com/SunQpark/SPIA2018_cycle_GAN`.

Chapter 2

Background

2.1 Related Models

There are two main approaches for image generation tasks: generative adversarial nets and variational autoencoder. In this project, only GAN-related methods will be considered and inplemented. The original GAN proposed by Goodfellow can train a generator to learn the real image distribution by training a discriminator together, which can tell the difference between real images and fake images.

In the field of image translation trained with unpaired image datasets, 3 models, CycleGAN, DiscoGAN, DualGAN are doing the same thing from high level perspective. They train two generative models to learn the mapping between two image domains by training two discriminators at each domain together and considering the cycle-consistency loss, which ensures ignorable difference between images and reconstructed images.
In detail, the differences are CycleGAN uses instance normalization, patchGAN discriminator. To stabilize the training, use least square GAN. Replay buffer no random input z no drop out; L1 distance as cycle consistency

DualGAN use generator and discriminator of pix2pix; no random input z but implemented drop out; use wgan; L1 distance as cycle consistency

DiscoGAN generator: conv, deconv and leaky relu; discriminator:conv+leaky relu L2 distance as cycle consistency

2.2 Evaluation Metric

'Inception Score' [10]

"We apply the Inception model1 [19] to every generated image to get the conditional label distribution p(y—x). Images that contain meaningful objects should have a conditional label distribution p(y—x) with low entropy. Moreover, we expect the model to generate varied images, so the marginal R

$$p(y|x = G(z))$$

dz should have high entropy. Combining these two requirements, the metric that we propose is:

$$exp(E_x KL(p(y|x)||p(y)))$$

, where we exponentiate results so the values are easier to compare." While there are some of defeats [1]

Chapter 3

Processing Data

3.1 Collection and Refinement of Data

In this section, we will explain about the progresses of collecting and refining data we've gone through. Table 3.1 shows the composition of dataset we used in experiments. Unless mentioned otherwise, every dataset used in experiments composed as the proportion as Set1 in table.

Dataset	Sketch			Photo
	Collected	CUFS	Sketch Filter	Celeb A
Set1	920 (30.8%)	571 (19.2%)	0 (0.0%)	1500 (50.1%)
Set2	920 (16.8%)	571 (10.4%)	1000 (18.2%)	3000 (54.6%)

Table 3.1: Number of images used for training in each component.

More details on each sources of data will be provided in following sections.

3.1.1 Photograph

For realistic photographs of human faces, we used Celebrity A [7] which contains more than 200,000 images of celebrity in the world. In addition to having clean images of human faces, this dataset contained 'attributes', some additional imformation of images. Though those informations were not used directly as input to our neural networks, they were useful in some progress of preprocessing. We will describe about the details in 3.1.3.

3.1.2 Sketch

The main portion of sketch image dataset we used was collected from Google Image search engine. However, the collected images were highly inconsistent, which was undisirable. figure shows some bad examples of image which were included in the first collection. Thus, these images has gone through preprocessing steps, which will be described in next section 3.1.3 After preprocessing steps, these images were aligned as fig 3.1

We also used CUHK(The Chinese University of Hong Kong) face sketch database(CUFS) [12], containing about 500 face sketches. Although this dataset also provides face photographs paired with the sketch images, we only used the sketch images to train our model to keep it from overfitting to these paired images.

Examples of images in each dataset can be seen in fig.

3.1.3 Preprocess

Figure 3.1: Preprocessing examples. Original images containing faces(top) and results after preprocessing steps(bottom)

In this section we deals with the preprocessing steps on face sketches and photos, which were applied separately before the training of model. By experiments of a few weeks, we found this part crucial to the performance of model. The first step of data refinement was to detect every faces for each image. By excluding images not containing recognized faces, we could get rid of 20% of bad examples in sketch database. Then, we applied 'facial landmark detection' for the detected faces, in order to get further information concerning the direction of head in the images. We utilized the 'dlib' framework [6] for those two steps. Next, we rotated the images to have faces aligned vertically using the detected locations of two eyes. Finally, the images were cropped to have faces in center and 30% of the width of head margins on both sides. The cropped images have 128 by 128 size in the end of preprocessings. Those steps were applied to both sketch and photo images to make them consistent in any attributes other than it is sketch or photo.

After some experiments we found that the model was learning to put smile on the generated photo from sketch images even when the original sketch images were not smiling. This seemed to be originated from the fact that images in photograph have smile in most case, while sketch images haven't. Since this was undisired effect, we reduced the ratio of smiling faces in the photograph dataset. This process was done

by checking attributes file which Celebrity A dataset provided to see wether given image is smiling or not and using only one images per 20 smiling images.

3.1.4 Generating Sketch Images

Chapter 4

Model Structure

4.1 Network Architectures

As we mentioned earlier, baseline structure mainly used in this project is Cycle-GAN. The Cycle-GAN consists of two GAN models, which learn to translate images from one domain to the other, one direction per each respectively.

4.2 Stabilization of GAN Training

wGAN
- dualGAN
- Instance / Batch normalization

Chapter 5

Result

Figure 5.1 shows some examples of result before the data refinement steps were applied. The results seems to contain some face-like objects, but the original faces in the sketch images were not properly translated, resulting in weired colorization in the result. The result of photograph to sketch translation also shows severe artifacts due to the mismatch of locations of faces between datasets.

Figure 5.1: Original input images(left) and result of translations(right) by networks trained before input data is not aligned. Image size is 256 by 256 and model is trained for 64 epochs.

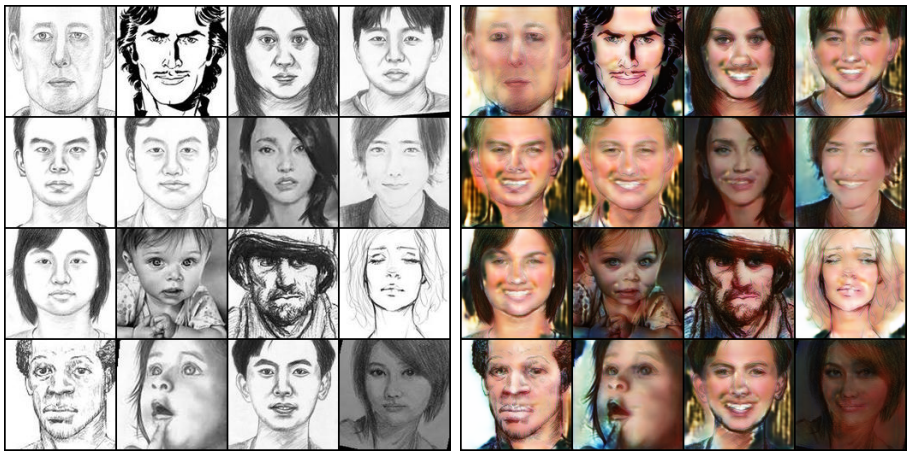

Figure 5.2: Original input images(left) and result of translations(right) by networks trained on datasets after face alignment, but before number of smiling faces was reduced. Image size is 128 by 128 and model is trained for 128 epochs.

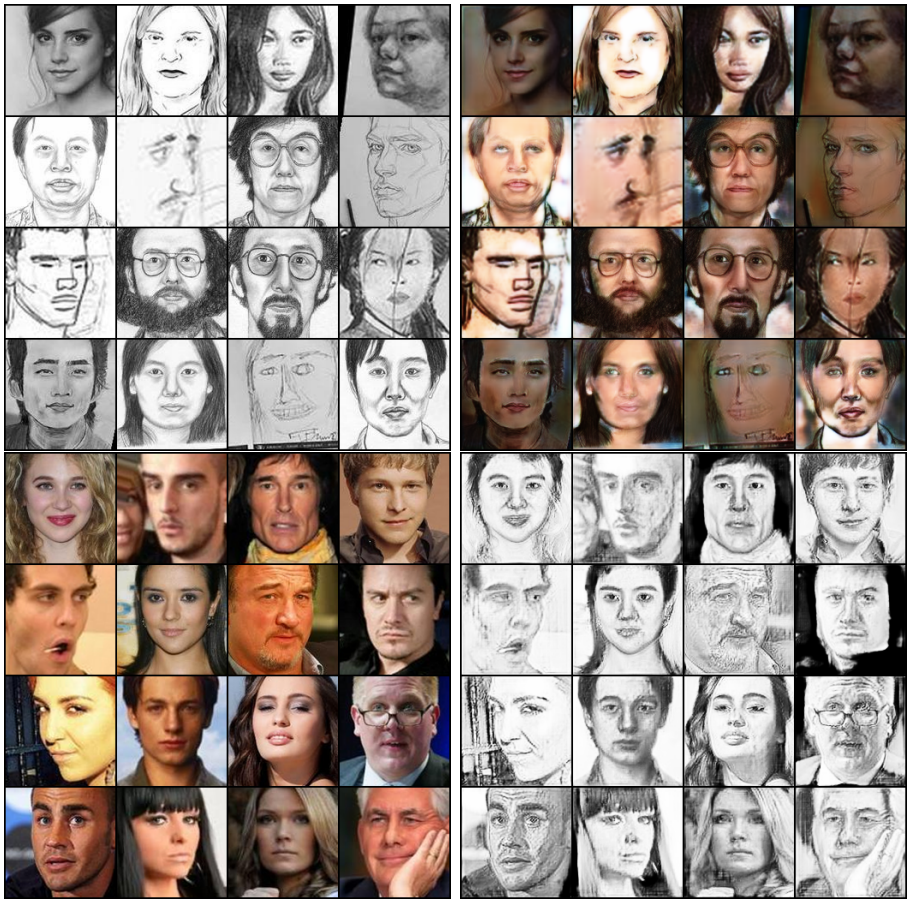

Figure 5.3: Original input images(left) and result of translations(right) by networks trained on datasets after face alignment and number of smiling faces was reduced. Image size is 128 by 128 and model is trained for 128 epochs.

Chapter 6

Conclusion

The point was made in the Acknowledgments section of this Sample Report that it is important to credit others whose work you use—it is a matter of professional ethics and courtesy. In addition to acknowledgment of broad assistance or contributions that you put into the Acknowledgments, you may also need to reference more specific contributions elsewhere in your text. Wherever a distinction is needed, make it clear which part of your work you have borrowed or adapted from others, and provide a reference to the source.

6.1 Acknowledgements

Our team would like to acknowledge Professor Yu-Wing TAI and Dr. Ningchen YING for helpful discussion. Professor Yu-Wing TAI offered a lots of helpful suggestions to model development such as implementing U-net as well as suggestion to data collection. Dr Ningchen YING offered a general introduction and outlining to the project and his patience to guide the project. We would also like to thank Professor Shingyu Leung, Professor Avery CHING, HKUST and SNU MATH department for providing computational resources and a sight seeing trip to Macau for stimulating our creativity.

Chapter 7

Reference

The following is a small collection of answers to questions RIPS students have asked.

1. **How do I open and modify LaTeX files, as well as view the results?**

   Several LaTeX typesetters are available on the IPAM network. The default options are activated by clicking on the main page for the report template,

   `z-Report-Master-2015.tex`

   The present version of the template is being maintained using the TeXworks typesetter "pdfLaTeX." For more information about other options, see the README file listed among the files used in construction this report.

   The template is divided into several chapters, appendixes and other files with functions identifiable by their names coded in LaTeX (files ending in ".tex") along with some graphics files coded as Encapsulate Postscript (".eps"). If you modify any one of these source files, you will need to run the typesetter on the main `z-Report-Master-2015.tex` file. See Chapter **??** for tips handling bibliographic references. And see Appendix B for location of the LaTeX sources relating to this sample report.

2. **Should I use a single-sided or double-sided format for my report?**

   Clearly, double-sided printing saves paper. But this is not as simple as it seems. Best to explain this in vocabulary used by publishers: *opening*, *recto*, and *verso*: An *opening* is the pair of pages you see when you open a book at random; the recto is the page on the right-hand side, and the verso is the page on the left-hand side — or, on a single leaf, recto is the front side and verso is the opposite side. When you open almost any book at the start of a new chapter, the first page of the chapter will appear on the right-hand page—*recto*. This is true whether or not the left-hand page of the opening—*verso*—is blank. That's the way it should be in your report. Each major section of your report, not just chapters, should begin on a recto.

   Rectos are always odd-numbered. Very likely, you will not get these results if you submit your single-sided report for double-sided copying on a printer. There are some LaTeX acrobatics you must specify to make your double-sided report

turn out with proper recto-verso pagination, the code for which is built into `z-Report-Master-2014.tex`; you will see which document class to use—and which to comment out—at the top of the file.

3. **What format should I use for my report for the editing process, and for the final copies?**

   See Chapter 8.

4. **How do I convert images (for example, in JPG, GIF, BMP, or PNG formats) to EPS?**

   There is a simple procedure using a "Terminal" on an iMac: just invoke the "`convert`" command and specify the source and target file and coding. Other methods can be complicated.

   Another possibility is to read them in MATLAB and export them to EPS from there. Here's a sample code:

```
A=imread('MyFigure.jpg');            % read the image
imshow(A);                           % show it on the screen
saveas(gcf, 'MyFigure.eps', 'psc2'); % export to color eps
```

   Note that this can create large EPS files. Simple diagrams are better recreated in INKSCAPE or MATLAB and then exported to EPS.

5. **What if a figure caption is too long to fit nicely in the list of figures?**

   Chapter **??** discusses figures in general; there you can see an example of how a figure caption is created. Ordinarily, the figure caption provides the text for the title for the figure in the report's List of Figures.

   But what if the figure caption is too long or otherwise inappropriate for using in the List of Figures? The solution is to include an alternative title in square brackets (before the curly brackets—braces) in the caption declaration:

```
\caption[Alternative title for List of Figures]{The caption
that appears under your figure; it can be more complex than
is appropriate for a title in the List of Figures.}
```

   The same technique is used for providing alternative titles for tables—and for running heads as well, although these are not used in your RIPS report.

6. **A useful little thing to know about fractions:** When you compose an inline fraction, sometimes it looks too small: $\frac{x}{y}$. Instead of using the LaTeX "`frac`" function, try "`dfrac`" to increase the size: $\dfrac{x}{y}$.

7. **Where can I find more information on LaTeX?**

   The internet is a great resource. Search and ye shall find! See, for example,

`http://latex-project.org/`

Or you may want to get one of the books listed in the Bibliography, for example, *More Math Into LaTeX* [**?**], or the *LaTeXCompanion* [**?**]. Your mentor most likely knows a lot of LaTeX too, so don't hesitate to ask for help.

8. **Where can I find standard references to resolve finer points of style?**

   There are many good references, but the RIPS director uses the 16th edition of *The Chicago Manual of Style* [**?**] and its companion *A Manual for Writers of Research Papers, Theses, and Dissertations: Chicago Style for Students and Researchers* [**?**] as references of first resort, followed by the handy compact reference *Hart's New Rules* [**?**]. Other highly developed style guides are the *MLA Handbook for Writers of Research Papers* [**?**] and the *Publication Manual of the American Psychological Association* [**?**].

   The examples in Grätzer's *More Math into LaTeX* [**?**] can also be used to resolve some style questions as well as questions about LaTeX coding. See the bibliography pages for other good resources.

9. **How should I punctuate itemized and enumerated lists?**

   Here's a rule that gets broken easily because the items in a list are sometimes not just a single phrase or sentence. Usually you will introduce your list with a sentence or phrase that ends with a colon. In that case:

   - begin each item with a lower-case initial letter;
   - terminate all but the last sentence with a semicolon or a phrase with a comma;
   - end the last sentence or phrase with a period.

   Here's an example that shows how any rule starts to get tricky:

   - begin each item with a lower-case initial letter;
   - terminate the last sentence with a semicolon or a phrase with a comma,
   - but end the last sentence or phrase with a period.

   I think the comma at the end of the second item is correct, but you may be tempted to place a semicolon there to be consistent. And in case you have more than one sentence, or a mixture of a sentence and a phrase on a single line, What then? I'd prefer to avoid the latter complication if possible by make each item a simple sentence or phrase, and use only sentences or only phrases in a single list.

10. **Are there standard fonts for representing filenames, file extensions, URLs?**

    In this document we have used `teletype` for filenames and SMALL CAPS for file extensions, program names, and the names of software packages. For URLs, we use `teletype`.

11. **How do I write the `tilde` symbol?**

Just hitting the tilde key on the keyboard won't work, as that character is special to LaTeX. Instead, use the `\sim` command, which gives $\sim$. The reason the plain keyboard tilde character is special is that it is used for a non-breaking space, e.g., by writing

```
Dr.~Jones
```

instead of simply

```
Dr. Jones
```

This is how to tell LaTeX never to break a line after `'Dr.'` with `'Jones'` starting at the beginning of the next line.

12. **LaTeX and BibTeX reserved characters**

These characters are interpreted in special ways by LaTeX typesetters:

$$\# \ \$ \ \% \ \hat{} \ \& \ \_ \ \{ \ \} \ \tilde{} \ \backslash$$

You may print them in your text by "escaping" them with the backslash (\), e.g., use \# in your LaTeX code. If not properly escaped, these characters can cause mysterious errors, especially in BibTeX files because the source of the error can be inadequately-referenced by LaTeX.

13. **Why do BibTeX `bib` files so often fail to compile?**

If you have not used BibTeX before, you may find it a bit difficult getting used to it. It's not a part of LaTeX, so it requires some special handling. Most LaTeX users find it to be worth the effort, since it allows them to keep their references in a separate file (or files) that can easily be re-used. BibTeX makes it easy to reference items and to present them in a consistent format.

No doubt about it, BibTeX does have some fussy features. For example, your reference list will crash if it contains reserved characters, e.g., in URLs. The point of confusion is that some characters reserved by BibTeX are not reserved elsewhere or the normal methods of escape don't work, so these characters can be pesky and catch you unawares. Here are some character encodings that are useful as alternatives in your bib file:

- use {`\&`} for *ampersand*;
- use {`\_`} for *underbar*;
- use {`\sim`} for *tilde*.

The curly brackets are not strictly necessary, but they are used to avoid needing a space before a character that follows the symbol.

Which bibliographic style should I use?

There are many options. For example, the *siam* and *ieeetr* styles produce good results for RIPS reports.

Your bibliography should distinguish book titles by printing them in *italic* font. But titles of written materials that appear within a collection such as journal articles are distinguished by surrounding them with double quote and are preferably printed in *roman* font, and preferably the title of the *collection* is italicized.

Both the "siam" and "ieeetr" italicize book titles. However they treat article and collection titles, and multiple entries by the same author, differently.

The advantage of the "siam" style is that it aggregates books or articles by the same author in reverse-chronological order under a single author entry. A disadvantage is that it also italicizes article titles and does not quote them, and it prints collection titles in roman font. The quotation problem is easily solved by your supplying them in your `bib` file by surrounding the title with two back quotes on the left and two apostrophes on the right, but you cannot switch the italic and roman fonts, which is unfortunate but acceptable.

An article is cited here as an example using the "siam" bibiliographic style: "A Set of Postulates for Plane Geometry (Based on Scale and Protractors)" by G. D. Birkhoff [**?**]. Take a look at the `bib` file to see how it was necessary to surround the title of the article with quotes; moreover, curly braces were used to prevent BibTeX from reducingl the capital letters in the title to lowercase.

The "ieeetr" style differentiates book and article titles, and titles for articles in collections, correctly. However, if there are multiple books or articles by an author, "ieeetr" awkwardly tosses additonal entries to the end.

Check the available options to make sure you can get a good result.

14. **Where do inline citations go within the "body text"?**

The *body text* or *running text* is the main text in a book or report; it excludes chapter and section heads, front matter, back matter and sometimes, depending on context, footnotes and captions. Generally, it's what the author wrote and not the text supplied by the publisher. For the purpose here, I include footnotes and captions.

The Chicago Manual of Style [**?**] is silent on where to place inline citations, whether within a sentence or after the period, but Turabian gives examples of citations within sentences and none after the period [**?**]. According to *The Chicago Manual of Style* you can do something like this for a block quotation — note that there are no quotation marks, and authorship (or citation) is dropped in parentheses below the quotation:

> O for a Muse of fire, that would ascend
> The brightest heaven of invention,
> A kingdom for a stage, princes to act
> And monarchs to behold the swelling scene!
>
> (Prologue to "Henry V" by William Shakespeare)

15. **How do I control the page placement of figures and tables?**

The placement algorithms in LaTeX are complicated. The GRAPHICX package used by the RIPS Master Template is discussed in extensive detail in the athoritative "Using Imported Graphics in LATEX and pdfLATEX" by Keith Reckdahl at

`http://ctan.math.washington.edu/tex-archive/info/epslatex/english/epslatex.pdf`

For a start, see Sections 18 and 19: "Customizing Float Placement" and "Customizing the Figure Environment." Note especially Section 21, "Non-Floating Figures:"

> Since non-floating figures can produce large sections of vertical whitespace, non- floating figures are generally considered poor typesetting style. Instead, users are strongly encouraged to use the figure environments `[!ht]` optional argument which moves the figure only if there is not enough room for it on the current page.

See the internet for other solutions, e.g., for fixing gross placement errors using commands like: `\raggedbottom, \baselinestretch, \parskip`.

16. **How long should my report be?**

Depending on how formal you choose to make your midterm report, it can evolve into the final report, so the latter will usually be longer than the midterm report but not necessarily. The dissertation of at least one Nobel Laureate was under thirty pages in length, so it is possible to report winning results succinctly. Here's a rule of thumb:

Just decide what points you want to make, and then make all your points in clear language, using figures and tables wherever they facilitate understanding. It's hard to be succinct when you don't have a lot of time to prune your text. But try to be as brief as possible without injuring clarity.

After you have done that, check to see whether your report has all the major ingredients described in this Sample Report, especially in Chapters 1 & 2. Considered as a draft on its way to becoming the final report, the midterm report may be written a little more loosely and contain things that you may decide to prune later.

If everything is there, including the extra pages created by LaTex, such as table of contents, list of figures, list of tables, as necessitated by your text, then that's how long your report should be.

Chapter 8

Appendix

Writing a good report is a serious challenge, requiring time and attention to details that are easily and often greatly underestimated by inexperienced writers. So how does a good report acquire its final polish?

Your academic mentor will help guide your writing throughout your project. He or she will be the first to review your report draft and edit it not only for style but also for technical correctness. After you have satisfied your academic mentor with your draft, you will submit it to the RIPS program director for *copy editing*, who will attend to matters of readability, grammar, and style. After you submit your drafts for their review, it is likely they will return it to you with corrections, crossed out text, and possibly even suggestions for overhauling whole parts of it. That is normal editing practice, and it is an expected part of the process of writing a professional-quality document.

Since your report is sponsored work, your sponsoring liaison should be given an opportunity to review it before its release. But here's an important caution: Don't submit a draft to your sponsor until *after* it has been revised in compliance with suggestions from your academic mentor and the RIPS director. It's good practice to give sponsors your most professional efforts—not your first drafts. After you have satisfied the editing requirements of your academic mentor and the RIPS director, you should send your sponsor a `pdf` of a copy by email for review. Your sponsor may suggest further changes.

You will facilitate the process of editing your report by submitting a single-sided printed copy for editing. Double-sided is too hard to work with. Although it is typical for copy editing to use double spacing of a manuscript to allow for editorial comments between lines, it is unnecessary for a RIPS report. A table of *proofreader's marks* used by copy editors for mark-up, and used sometimes here at IPAM, is referenced in Appendix B.

After you have completed all the edits required by your academic mentor and the RIPS director, you can prepare final copies in two formats, respectively: (1) a single-sided `pdf` as an electronic copy, which you can email to your sponsor, and (2) a slim double-sided copy for the final print version — you can print this in the fatter single-sided format if your figures or text bleed through to the flip side of the page. See Chapter 7 for a discussion of the special pagination requirements for double-sided

copying.

Note that when you use Adobe Reader for printing your `pdf`, you are presented with options for *page scaling*. You may have to play with this to get the margins right.

Appendix A

BibTEX Sample Records, Record Types and Fields

Appendix B

Where to find this sample RIPS report?

Read-only LaTeX source code for the RIPS Report Template, sample Beamer slide presentations, and other LaTeX supporting materials are available at,

```
Computer ->  IPAM RIPS FOLDER -> on the R Drive under under "Templates-etc"
```

Your report will be "copyedited", i.e., edited for conformance to the RIPS *House Style*. For reference, a table of proofreader's marks that may be used for markup of your draft is included. It was copied from *The Chicago Manual of Style, 16th ed.* (See original source at: `www.chicagomanualofstyle.org/tools_proof.html`.)

Appendix C

Glossary

Page vs Leaf: In bookbinding, a trimmed sheet of paper bound in a book; each side of a leaf is a **page**.

Opening: The two pages you see when you open a book. The right-hand **page** is the **recto**—and the left-hand page is the **verso**.

Recto: The front side of a **leaf**; in a book or journal, a right-hand page. To **start recto** is to begin on a recto page, as any major section—e.g., title page, table of contents, preface, chapter, appendix, bibliography—normally does. Contrast **verso**.

Verso: The back side of a **leaf**; the **page** on the left-hand side of an **opening**.

Front matter: As applied to this report, the material that appears in the front of the document, including title page, the abstract, acknowledgments, table of contents, list of figures, list of tables, usually numbered with lowercase roman numerals. RIPS reports initiate pagination with 1 in the front matter and proceed throughout with arabic numerals. This variation of usage is allowed because modern typesetting permits easy re-pagination after pages have been added to the front matter, something not easily done—after completion of the main matter—when typesetting was done by hand.

Main matter: The main part of the document, including the appendixes. **Page** numbers start from 1 using arabic numerals if front matter is enumerated using roman numerals.

Back matter: Material that appears at the back of the document, which in our report includes only the Bibliography.

Appendix D

Abbreviations

IPAM. Institute for Pure and Applied Mathematics. An institute of the National Science Foundation, located at UCLA.

RIPS. Research in Industrial Projects for Students. A regular summer program at IPAM, in which teams of undergraduate (or fresh graduate) students participate in sponsored team research projects.

UCLA. The University of California at Los Angeles.

Selected Bibliography Including Cited Works

[1] S. Barratt and R. Sharma, *A note on the inception score*, 2018.

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