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USING REGRESSION TECHNIQUES TO CORRELATE WEATHER SIGNALS

WITH IMAGE SEQUENCES

by

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ABSTRACT OF THE THESIS

Using Regression Techniques to Correlate Weather Signals with Image Sequences

by

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Master of Science in Computer Science

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Webcams are cheap sensors that capture a potentially large amount of information about a scene. This thesis considers the use of regression and correlation techniques such as Canonical Correlation Analysis (CCA) to convert these webcams into environmental sensors and predict the values of weather signals. Local environmental properties often directly affect the images we collect from the webcams; whether it is cloudy or sunny is visible by the presence of shadows; wind speed and direction is visible in smoke, flags, or close up views of trees; particulate density is reflected in haziness and the color spectrum during sunset. Using the AMOS database, which has been archiving nearly 1,000 webcams every 30 minutes for the last 3 years, we explore relationships between the amount of training data and the accuracy with which we are able to infer the values of certain weather signals including wind speed & direction and vapor pressure from inherent properties in the image. This allows the webcams *already* installed across the earth to act as generic sensors to improve our understanding of local weather patterns and variations.

Acknowledgments

First and foremost, I would like to thank Dr. Robert Pless, who has been my research and faculty adviser for the last four years. His constant attention and guidance have been crucial in the construction of this thesis and I am extremely grateful for all of his help. My experience working under him in the Media & Machines Lab is one of the most valuable of my college career and has taught me skills that I will surely use after I graduate.

I would also like to thank Nathan Jacobs and many other students who helped review this thesis and the related research as well as Dr. William Smart and Dr. Ron Cytron for sitting on my Thesis Committee along with Dr. Pless.

Finally, I would like to thank the Department of Computer Science & Engineering for promoting and providing many opportunities for undergraduates to get involved in research projects. I have benefited greatly from working in a research lab during my time here and that would not have been possible without the department's commitment to undergraduate research.

Richard Speyer

Washington University in Saint Louis
May 2009

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Chapter 1

Thesis Format

The following guidelines offer you some degree of flexibility in formatting your thesis. Options are summarized in Table 1.1. Whatever options you choose to use, you must use them consistently throughout document.

1.1 Margins

Your printed output must reflect a physically measurable left margin of at least 1.5 inches, with top, bottom, and right margins measurable at 1 inch. Some systems' settings produce varying results when printing to different printers, so be sure to measure your output. Remember, nothing (not even page numbers) should print in the margins.

1.2 Page Numbers

Number all pages in your thesis except the title page and the optional copyright page which might follow the title page. Number the "front matter" pages (i.e., the pages that come prior to the main body of text, prior to chapter 1) with lowercase Roman numerals, centered immediately above the bottom margin, and starting with the Roman numeral "ii". Number the pages starting with the first page of the first chapter with Arabic numerals, also centered immediately above the bottom margin, and starting with numeral "1".

1.3   Body Text

Use a 10, 11, or 12-point Garamond, Times Roman or Times New Roman font for your thesis text. (The MicroSoft WORD based "template" uses Garamond throughout, and is recommended whenever possible. The LATEX version uses a high quality variation of the Times Roman font. Whichever is used, be consistent throughout your document..) Use 1.5 or double line spacing for most body text. Block quotes should be single spaced. Use either left justification with a ragged right edge, or full justification. Paragraphs may be set in a block style, with no indentation, or they may be indented up to 0.5 inch. Skip a line between paragraphs.

1.4   Titles and Headings

Titles and headings may be left-justified or centered. Capitalize the first letter of the first word and the first letter of each subsequent major word in a title or heading. Do not capitalize articles, prepositions, and conjunctions that are not the first word of a title or heading. For example, do not capitalize such words as the following: a, an, the, for, to, on, or. Formatting specifications for particular types of headings and titles are described below. You may use a plain or bold version of the body text font for all titles and headings.

1.4.1   Chapter Titles

Begin each chapter on a new page. You may start the chapter title below the top margin (1.5 inches from the top edge of the page), or you may leave some space and start the chapter title up to 3 inches from the top edge of the page. There are two options for formatting the chapter title:

- Type the word "Chapter" followed by the chapter number, skip a line, and type the chapter title on the following line; or

- Type the chapter number followed by the chapter title, all on the same line.

You may use a font size of up to 36 points for the chapter title.

1.4.2 Section Headings

You may use a font size of up to 24 points for the section headings. Type the chapter number and section number before the section title.

1.4.3 Subsection Headings

You may use a font size of up to 18 points for subsection headings. Type the chapter number, section number, and subsection number before the subsection title.

1.4.4 Headings for Divisions Smaller than Subsections

Use unnumbered headings for divisions smaller than subsections. You may use a font size of up to 14 points. Headings may be typed above or on the same line as the sections they label. You may use both styles within your thesis.

Run-in Headings   To the left is an example of a run-in heading. Notice that it is typed on the same line as the section that it labels. It may be used for divisions smaller than subsections.
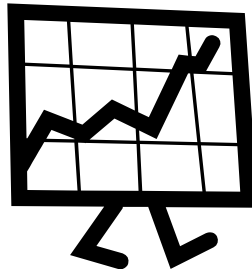
Figure 1.1: Just a Figure

1.5   Figures and Tables

Figures and tables must be referenced in the text by number. They must be numbered consecutively throughout each chapter, with the chapter number preceding each figure or table number. For example, the third figure in chapter 1 would be labeled Figure 1.3. You may either:

- Maintain one numbering sequence for figures and another for tables, and label figures with the word "Figure" and tables with the word "Table"; or

- Label both figures and tables with the word "Figure" and maintain one numbering sequence.

Place figures and tables as close to their references in the text as possible. Place a figure number and title below each figure (or table labeled as a figure). Place a table number and title above each table labeled as a table. In figures and tables, avoid using color and avoid text smaller than 10 points. Do not let figures or tables spill out into the margins. Figure 1.1 is an example figure.

1.6   Lists

You may include lettered, numbered, or bulleted lists in your thesis. Use consistent punctuation and capitalization throughout each list. Lists may be indented.

1.7   Footnotes and Endnotes

You may use footnotes or endnotes for brief notes that are not appropriate for the body of the text. Use either footnotes or endnotes consistently throughout your thesis. Position footnotes in 10 point type just above the bottom margin and page number. Use a short horizontal rule to separate footnotes from the text. Position endnotes at the end of each chapter. Type endnotes using the same font size and justification as

the body text. Single space within each footnote or endnote; double-space between footnotes or endnotes. Footnotes and endnotes should be consecutively number.

1.8 Quotations

You must use quotation marks and parenthetical references to indicate words that are not your own. Put quotation marks around short quotes. Put long quotes in separate single-spaced paragraphs, indented up to 1 inch from the left margin (these are called block quotations). Kate Turabian, editor of official publications and dissertation secretary at the University of Chicago for over 25 years, distinguishes short and long quotes as follows:

> Short, direct prose quotations should be incorporated into the text of the paper and enclosed in double quotation marks: "One small step for man; one giant leap for mankind." But in general a prose quotation of two or more sentences which at the same time runs to four or more lines of text in a paper should be set off from the text and indented in its entirety.... [10]

1.9 Equations

Equations may be set in-line with the text or numbered and placed in separate paragraphs. Use the same numbering style for equations as you would for figures and tables. Here is an example of an equation set in-line with a paragraph: $E = mc^2$. Here is an example equation placed in a separate paragraph:

$$E = mc^2 \tag{1.1}$$

Equation numbering and formatting should follow the usual convention of your discipline and be acceptable to your thesis committee.

Table 1.1: Thesis Formatting Options

Thesis Element	Formatting Options
title page font	12-point or 14-point Garamond, Times or Roman
table of contents chapter title font	bold or plain
first-level table of contents indentation	0 to 0.5 inch
second-level table of contents indentation	0 to 1.0 inch
body text font	10, 11, or 12-point Garamond, Times or Roman
body text line spacing	1.5 or 2
body text justification	left or full
paragraph indentation	0 to 0.5 inch
chapter title position	1.5 to 3 inches below top edge of page
chapter title style	heading preceded by the word "Chapter" and the chapter number or, heading preceded only by the chapter number
chapter title	10-pt to 36-pt font, centered or left-justified, plain or bold
section heading	10-pt to 36-pt font, centered or left-justified, plain or bold
subsection heading	10-pt to 36-pt font, centered or left-justified, plain or bold
unnumbered headings	10-pt to 36-pt font, centered or left-justified, plain or bold
table labels	label tables as "Table" or "Figure"
Parenthetical reference style	author-date system, numbered, or another style acceptable to your committee
Reference list style	any style acceptable to your committee

Chapter 2

Parts of the Thesis

This chapter describes the components of a thesis. You need not include all components described here, but you must follow the prescribed order for the components you do include. Table 2.1 lists the required and optional components in the order that they should appear. Your thesis should include three main parts: the front matter, the text, and the back matter. Each of these parts is described below.

2.1 Front Matter

The front matter includes all material that appears before the beginning of the main text. Number all "front matter" pages (except the title page and the optional copyright page) with lower-case roman numerals, centered just above the bottom margin. Each of the following sections should begin on a new page.

2.1.1 Title Page

Format the title page precisely as the title page to this document is formatted: include a 1.5-inch left margin, a 1-inch top margin, a 1-inch right margin, and a 1-inch bottom margin. Use a 12- or 14-point regular Garamond, Times or Roman font on this page. If you are writing a dissertation, substitute the word "dissertation" wherever the word "thesis" appears in this document. The date on the title page should reflect the month and year the degree will be awarded and should be one of the following months: December, May, or August. Do <u>not</u> number the title page.

Table 2.1: Required and Optional Thesis Components

Major Part	Thesis Component	Required	Optional
Front Matter	Title Page	●	
	Abstract Page	●	
	Copyright Page		●
	Dedication		●
	Table of Contents	●	
	List of Tables	(Rqrd if used)	
	List of Figures	(Rqrd if used)	
	List of Abbreviations		●
	Glossary of Nomenclature		●
	Acknowledgments		●
	Preface		●
Text	Chapters		●
Back Matter	Appendices		●
	References	●	
	Vita	●	
	Short Title Page	●	

2.1.2   Copyright Page

Include a copyright page if you plan to copyright your thesis. If used, the copyright page must be unnumbered, immediately following the title page. It should include three lines, centered on the page with regular body text font and spacing. The 1st line should be "copyright by", the 2nd line should contain your full name. The 3rd line should contain the year the degree is to be awarded. Do not number the copyright page. If you are an Master's candidate and would like to register your claim to copyright your thesis, you must make all arrangements independently. Doctoral students will complete a publishing agreement form which will give them a copyright registration option.

2.1.3   Abstract Page

The abstract must be 350 words or fewer. Format the abstract page precisely as done in this document. The abstract page always begins the document's page numbering at "ii".

2.1.4 Acknowledgments

An acknowledgments section should be included.. Use it to thank those who supported your research through contributions of time, money, or other resources. Type the word "Acknowledgments" in chapter title style at the top of page. If the acknowledgments fill more than one page, put the heading only on the first page. Number the page with a Roman numeral, centered at bottom, sequentially following the abstract page(s) Roman numeral(s).

2.1.5 Dedication

The dedication page is optional. If you decide to include a separate dedication page, make it short and center it on the page. If included, you should number it, placing the next logical/sequential Roman numeral at bottom of page, centered, as shown in this sample document.

2.1.6 Table of Contents

The table of contents must include the page numbers of all chapters and sections of your thesis. In addition, it may include the page numbers of all subsections. It must also include the page numbers of all front and back matter elements, unless otherwise specified. Chapter titles should appear flush left, section headings may be indented up to 0.5 inch, and subsection headings may be indented up to 1 inch. Chapter titles may be typed in plain or bold font. All titles and headings must be followed by a dot leader and a page number. The word "Contents" must appear in chapter title style at the top of the page. Be sure to align multi-lined chapter titles in the table of contents. For example, when a table of contents' chapter or section title extends to a second line, be sure that the 1st character of the 2nd line aligns immediately under the 1st character of the title/chapter/section name on the line above it (i.e., as done in this sample document's table of contents, and as specifically illustrated in the "list of tables" page for table 2.1). Make certain, too, that these long titles also align nicely within the body of text, where multi-lined chapter titles or section titles

should still break at a logical point and align in a manner allowing the titles to be read clearly without confusion. Sometimes, for long chapter or section titles, this will mean forcing a line break at a logical point. This cannot be automated, but relies on your own good judgment. A good example of a multi-lined title can be found at the top of Appendix A; notice how the two lines are deliberately divided helping each phrase to be read easily and fluidly.

2.1.7 List of Tables

Include a list of tables only if your thesis actually contains tables. Format the list of tables the same way the table of contents is formatted, but put the word "List of Tables" in the heading.

2.1.8 List of Figures

Include a list of figures only if your thesis actually contains figures. Format the list of figures the same way the table of contents is formatted, but put the word "List of Figures" in the heading.

2.1.9 List of Abbreviations

Include a list of abbreviations only if you use abbreviations that are not common in your field. Arrange the list alphabetically. Type the word "List of Abbreviations" in chapter title style at the top of the page.

2.1.10 Glossary or Nomenclature

Include a glossary or nomenclature section only if your thesis contains technical words that are not commonly used by people in your field. Type the word "Glossary" or "Nomenclature" in chapter title style at the top of the page. The glossary or nomenclature section should consist of an alphabetized list of words and their definitions.

2.1.11 Preface

A preface is optional. If you include a preface, use it to explain the motivation behind your work. Format the preface the same way the acknowledgments section is formatted, but use the word "Preface" in the heading.

2.2 Text

The text part of the thesis should be divided into numbered chapters, sections, and subsections. Use Arabic numerals for this numbering. Divisions smaller than subsections may be used, but they should not be labeled with numbers. Place Arabic page numbers throughout the body of text centered just above the bottom margin.

2.3 Back Matter

Throughout the back matter, use the same Arabic page number formatting as used in the body of text section.

2.3.1 Appendices

Appendices may be used for including reference material that is too lengthy or inappropriate for the thesis text. If one appendix is included, an appendix title is optional. If more than one appendix is included, each one should be titled and lettered. In general, appendices should be formatted like chapters. However, they may be single spaced or include photocopied material. If photocopied material is used, you must add page numbers at the bottom, putting those page numbers in square brackets to indicate that they are not part of the original document.

2.3.2 References

The reference section should follow the final appendix (or the conclusion of the text if there are no appendices). Type the word "References" in chapter title format at the top of the page. Single space within references and double space between them. More information on formatting references is included in Chapter 3.

2.3.3 Vita

Your vita should include your name, relevant academic and professional achievements, and current month and year. It may also include your date and place of birth, publications, and professional society memberships. Your vita should be the last page of your thesis.

2.3.4 Short Title Page

The short title page should be prepared as described in Appendix B.

Chapter 3

Citing References

In the References section at the end of your thesis, list references cited using the style recommended in *The Chicago Manual of Style* [11] or another style acceptable to your committee. Insert parenthetical references where the reference material is referred to in the text. This chapter explains how to format references according to *The Chicago Manual of Style*. If you use a different style, you should obtain the appropriate style rules. For example, most journals periodically print instructions for authors that include reference style rules.

3.1 Parenthetical References

References should be cited at the position in the text where they are noted. *The Chicago Manual of Style* [11] recommends two systems for citations. You may use either of these systems or an alternative system acceptable to your committee.

3.1.1 Author-Date System

In this system, the last name of the author and the year of publication appear in parentheses following the quoted text. If the reference is alphabetized in the References section by its editor, publisher, or organization, then the name it is alphabetized under is used in place of the author. Some examples follow:

- Single author: (Smith 1993)

- Two authors: (Jones and Yang 1991)

- Three authors: (Jones, Smith, and Yang 1984)

- Four or more authors: (Johnson et al. 1994)

- Organization as author: (Association for Computing Machinery 1989)

- Two works referenced in one sentence: (Black 1994; Smith 1993)

3.1.2 Numbered References

In this system, the reference number appears in square brackets following the quoted text. This system is used throughout this document.

3.2 Reference List

References should be listed in alphabetical order by the last name of the first author (or organization or publisher, if no author is given). If the numbered reference style is used, the reference list should obviously be numbered as well. Several example references are listed in this document's reference list. Most of these references are taken from *A Manual for Writers of Term Papers, Theses, and Dissertations* [10].

Appendix A

The English Language and Other Confusing Things

While this guide answers most questions about how to format a thesis, it does not address questions about English grammar, use of abbreviations, punctuation, spelling, and other confusing subjects. Students should obtain a dictionary and a style of grammar book to refer to as questions arise. The dictionary is important because most electronic spelling checkers are not complete and do not contain definitions. (You may also need to refer to some of the references you cite for the spelling of technical terms.) The grammar or style book is useful for checking grammar and punctuation rules. A good style manual contains information about correct English usage as well as advice for preparing a manuscript. *A Manual for Writers of Term Paper, Theses, and Dissertations* [10] is one such concise and inexpensive manual based on the lengthy and more expensive *Chicago Manual of Style* [11].

The following rules will help you avoid three mistakes frequently made by students:

- Hyphenated words must begin and end on the same page.

- When a page break falls in the middle of a paragraph, at least two lines of text from that paragraph must appear on the second page.

- At least one line of text from a section or subsection must appear on the same page as the title of that section or subsection.

Appendix B

Procedures and Deadlines

Deadlines At least one semester prior to the semester in which you believe you will complete all requirements for your degree, please be sure to consult with your department's graduate administrative assistant or coordinator to be sure you are aware of all requirements and deadlines with regards to your thesis and the submission of your thesis. Deadlines are printed in the course listings schedule book and are posted online. If you cannot make certain deadlines, you may have to postpone your graduation accordingly. M.S. and D.Sc. students have a special deadline by which they must submit an initial draft of their thesis so that it can be reviewed for formatting, to make sure it conforms to the essential formatting requirements, as illustrated in this sample guide. Ph.D. students must follow the requirements of the Office of Graduate Students in Arts and Sciences (GSAS). The GSAS office does not have an special formatting deadlines, but you should still contact that office if you have questions about your formatting.

Oral Examination Each member of the oral examining committee must be given a copy of the thesis or dissertation, in final form, in sufficient time to study it before the oral examination. Members of the examining committee have the right to request rescheduling of the examination if these copies are not made available to them at least one week in advance of the scheduled examination date. Copier paper may be used for these preliminary copies.

Final Copies After the oral defense, final copies of the thesis or dissertation approved by the examination committee and department are to be distributed as follows,

on or before the date stated in the current academic calendar. All final copies must be printed using only one side on high-quality (either watermarked or specifying as having 10-25% cotton), 8.5 x 11 inch white paper, and minimum 20-pound weight. Students should submit their final materials to the office(s) listed in the first item below, plus all other materials itemized below should be submitted accordingly, if needed:

- Four copies of the thesis or dissertation need to be submitted as follows: Each should be placed in a separate manila envelope with a copy of the title page securely attached. One of these two will be retained in the Washington University library; another will be sent back to you after being professionally bound; the other two copies are for your advisor and department. Two copies (along with the following listed materials) get delivered to Engineering Student Services. Two copies get delivered to your department (also with the short title page included as listed immediately below—although, none of the other additional items listed further below are needed for the department copies). **NOTE FOR PH.D. STUDENTS:** All four copies get delivered to the GSAS Office. See GSAS dissertation guidelines from their web site.

- a loose sheet containing (1) a short title of 35 letters or less (including spaces), (2) the author's last name, (3) the degree, and (4) the year of its award, centered on the page and punctuated as in the example.[1] This short title sheet is to be placed at end of your thesis/dissertation.

- one extra loose copy of the abstract (this applies to doctoral students only), double spaced, for publication in Dissertation Abstracts.

- one extra loose copy of the title page (this applies to doctoral students only) for the microfilming contract.

- the original **and** a photocopy of the University Microfilms Inc. publishing agreement contract (this applies to doctoral students only). This contract is available from the Engineering Student Services web site. If a registration to your claim to copyright is desired, attach a certified check, cashier's check, or money order for the current price listed in the University Microfilms contract. Personal checks

_____

[1]See the sample short title page for this document

are not accepted. The microfilming contracts are available in Lopata 324. The check or money order should not have an expiration date.

Four copies in all are to be submitted, as per details listed above. See the first bulleted item for full details. Please follow instructions carefully. Contact Engineering Student Services if you have questions. Ph.D. students may contact the Graduate School of Arts and Sciences.

Appendix C

Thesis Format Checklist

NOTE: If you have significantly varied formatting from that which is shown in this document, please complete this form and submit it to Engineering Student Servcies when you submit your thesis for format review.

Author's Name: _____

Title page font: ___ 12 point ___ 14 point

Table of contents chapter titled font: ___ plain ___ bold

First level table of contents indentation (0 to 0.5 inch): _____

Second level table of contents indentation (0 to 1 inch): _____

Body text font: ___ 10 point   ___ 11 point   ___ 12 point

Body text line spacing: ___ 1.5   ___ 2

Body text justification: ___ left   ___ full

Paragraph indentation (0 to 0.5 inch): _____

Chapter title position (1.5 to 3 inches below top edge): _____

Chapter title style: ___ with word "Chapter"   ___ without word "Chapter"

Chapter title: ___ (10 to 36 point)   ___ plain   ___ bold
                                               ___ centered   ___ left justified

Section heading: ___ (10 to 24 point)   ___ plain   ___ bold
                                               ___ centered   ___ left justified

Subsection heading: ___ (10 to 18 point)   ___ plain   ___ bold
                                               ___ centered   ___ left justified

Unnumbered heading: ___ (10 to 14 point)   ___ plain   ___ bold
                                               ___ centered   ___ left justified

Label tables as: ___ Table   ___ Figure

Reference list style (parenthetical, etc.): _____

Appendix D

Special Notes for LaTeX Users, Including a Demonstration of Wrapping Appendix Titles

It is strongly recommended that you use this file as a template for your thesis, since it greatly simplifies conforming to the required formatting standards.

There are several important points that students using the LaTeX version of this template should verify before submitting a thesis.

D.1 Front Matter

Much of the front matter (i.e., the Roman numbered pages) is automatically generated. Use `\renewcommand` command to customize the fields of these templates. For example, `\renewcommand{\thesisauthor}{your name here}` will customize the author name.

Most authors will need to customize the `\thesismonth`, `\thesisyear`, `\thesisauthor`, `\thesisauthorlastname`, `\thesisdefensedate`, `\thesistitle`, `\thesisshorttitle`, `\thesisdepartment`, `\thesisfield`, `\thesissupervisor`, and `\thesiscommittee` fields. Examples of these can be seen in the sample `thesis-main.tex` file.

You must also specify `phdthesis`, `dscthesis`, or `mastersthesis` when selecting the `\documentclass`. An example can also be seen in the sample `thesis-main.tex` file.

D.2   Table of Contents and Bibliography

The Table of Contents is automatically generated. `latex` should be run twice in succession after making any changes to the Table of Contents.

Due to the way LaTeX formats the Table of Contents, long appendix titles will not automatically wrap and indent properly. If you need to use a long appendix title, you must manually wrap and indent the appendix's table-of-contents entry. The `\wrappedappendix` command is defined in this template to assist with this; an example is seen at the top of the sample `thesis-appendixD.tex`. This requirement only applies to appendix titles: other section titles will automatically wrap properly, including entries in the List of Tables and List of Figures.

If changes need to be made to the Table of Contents' formatting, you can use the `\addtocontents` command to insert some formatting commands directly into the Table of Contents page. More significant changes can be made by editing the `.toc` file that LaTeX automatically generates. However, editing this file by hand is not recommended unless absolutely necessary, since it will automatically be re-generated the next time LaTeX is run.

Like the Table of Contents, the Bibliography is automatically generated. After editing the bibliography file, you should run `latex`; run `bibtex`; and re-run `latex` twice in succession.

D.3   Captions

Multiline captions will not automatically be centered. To correct this, place `\usepackage[center]{caption}` in the document preamble. The sample `thesis-main.tex` already includes this command.

D.4 Widows and Page Breaks

LaTeX may create widows if you have a paragraph followed by a list. To get rid of this widow, you must force LaTeX to break the page somewhere else. Either insert a \newpage command before the paragraph, or insert a \samepage command between the paragraph and the list.

LaTeX may also create widows in the Tables of Contents. You can force LaTeX to break the page in a more convenient location by inserting \addtocontents{toc}{\newpage} before the corresponding \chapter, \section, \subsection, or \subsubsection command in the text.

Excluding these two situations, LaTeX should not create orphans or widows. However, in some situations it may place page breaks at strange places — such as several inches above the bottom margin — in order to avoid creating orphans or widows. You can fix this by altering the \clubpenalty or \widowpenalty, or by manually adding \newpages where LaTeX guesses incorrectly.

References

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Vita

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May 2009

Learning to Find Signals in Image Sequences, Speyer, M.S. 2009