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2 Microcontroller-based Automated Watering System For Gardening with Moisture Sensor

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4 A Thesis
5 Presented to the Faculty of the
6 Department of Electronics and Communications Engineering
7 Gokongwei College of Engineering
8 De La Salle University

9

10 In Partial Fulfillment of the
11 Requirements for the Degree of
12 Bachelor of Science in Computer Engineering

13

14 by
15 CHUA, Sean Herbie P.
16 LIMQUECO, Jerald Steven G.
17 LU, Ervin Lester G.
18 QUE, Sean Wyndell T.

19 May, 2016



De La Salle University

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ORAL DEFENSE RECOMMENDATION SHEET

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This thesis, entitled **Microcontroller-based Automated Watering System For Gardening with Moisture Sensor**, prepared and submitted by thesis group, HERBS, composed of:

CHUA, Sean Herbie P.

LIMQUECO, Jerald Steven G.

LU, Ervin Lester G.

QUE, Sean Wyndell T.

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in partial fulfillment of the requirements for the degree of **Bachelor of Science in Computer Engineering (BS-CPE)** has been examined and is recommended for acceptance and approval for **ORAL DEFENSE**.

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Engr. Melvin K. Cabatuan
Adviser

35

May 29, 2016



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THESIS APPROVAL SHEET

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with group number HERBS in partial fulfillment of the requirements for the degree of **Bachelor of Science in Computer Engineering (BS-CPE)** has been examined and is recommended for acceptance and approval.

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PANEL OF EXAMINERS

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Date: May 29, 2016



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ACKNOWLEDGMENT

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Write this prior to hard binding if you have submitted all requirements and are told by your adviser that you have passed.



64

ABSTRACT

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Keep your abstract short by giving the gist/nutshell of your thesis.

66

Index Terms—microcontroller, automated, watering, system, gardening, moisture, sensor.



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131		
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165 ABBREVIATIONS

166	AC	Alternating Current.....	50
167	HTML	Hyper-text Markup Language	50
168	CSS	Cascading Style Sheet.....	50
169	XML	eXtensible Markup Language	50



NOTATION

171	\mathcal{S}	a collection of distinct objects	52
172	\mathcal{U}	the set containing everything	52
173	\emptyset	the set with no elements	52
174	$ \mathcal{S} $	the number of elements in the set \mathcal{S}	52
175	$h(t)$	impulse response	42
176	$x(t)$	input signal represented in the time domain	42
177	$y(t)$	output signal represented in the time domain	42

178 Throughout this thesis, mathematical notations conform to ISO 80000-2 standard, e.g.
179 variable names are printed in italics, the only exception being acronyms like e.g. SNR,
180 which are printed in regular font. Constants are also set in regular font like j . Functions are
181 also set in regular font, e.g. in $\sin(\cdot)$. Commonly used notations are t , f , $j = \sqrt{-1}$, n and
182 $\exp(\cdot)$, which refer to the time variable, frequency variable, imaginary unit, n th variable,
183 and exponential function, respectively.



184

GLOSSARY

185

- matrix a concise and useful way of uniquely representing and working with linear transformations; a rectangular table of elements 52



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Chapter 1

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INTRODUCTION

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218 1.1 Background of the Study

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264 **1.2 Prior Studies**

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275 **1.3 Problem Statement**

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285 **1.4 Objectives**

286 **1.4.1 General Objective(s)**

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288 **1.4.2 Specific Objectives**

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294 **1.5 Significance of the Study**

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304 **1.6 Assumptions, Scope and Delimitations**

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306 your assumptions as well.

307 **1.7 Description and Methodology**

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317 **1.8 Overview**

318 Provide here a brief summary and what the reader should expect from each succeeding
319 chapter. Show how each chapter are connected with each other.



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Chapter 2

321

LITERATURE REVIEW

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327 patents, notable conference papers) to prove that no one has done your work yet.

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373

2.1 Summary



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Chapter 3

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THEORETICAL CONSIDERATIONS

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425 3.1 Summary



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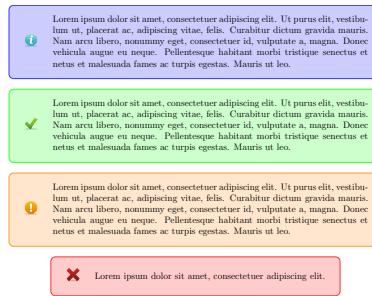


Fig. 3.1 A quadrilateral image example.



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Chapter 4

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DESIGN CONSIDERATIONS

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477 **4.1 Summary**



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Chapter 5

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METHODOLOGY

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486 5.1 Implementation

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5.3 Summary



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Chapter 6

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RESULTS AND DISCUSSION

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630 **6.1 Summary**



631 **Chapter 7**

632 **CONCLUSIONS, RECOMMENDATIONS,**
633 **AND FUTURE DIRECTIVES**

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636	7.2 Contributions	28
637	7.3 Recommendations	28
638	7.4 Future Prospects	30



7.1 Concluding Remarks

In this Thesis, ...

7.2 Contributions

The interrelated contributions and supplements that have been developed in this Thesis are listed as follows.

• the ;

• the ;

• the ;

7.3 Recommendations

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695 7.4 Future Prospects

696 There are several prospect related in this research that may be extended for further studies.
697 ... So the suggested topics are listed in the following.

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699 2. the
700 3. the



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Appendix A ANSWERS TO QUESTIONS TO THIS THESIS

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A1 How important is the problem to practice?

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A2 How will you know if the solution/s that you will achieve would be better than existing ones?

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A2.1 How will you measure the improvement/s?

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773 **A2.1.1 What is/are your basis/bases for the improvement/s?**

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783 **A2.1.2 Why did you choose that/those basis/bases?**

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793 **A2.1.3 How significant are your measure/s of the improvement/s?**

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803 **A3 What is the difference of the solution/s from ex-**
 804 **existing ones?**

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814 **A3.1 How is it different from previous and existing ones?**

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824 **A4 What are the assumptions made (that are be-**
 825 **hind for your proposed solution to work)?**

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835 **A4.1 Will your proposed solution/s be sensitive to these as-**
 836 **sумptions?**

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846 **A4.2 Can your proposed solution/s be applied to more general**
 847 **cases when some of the assumptions are eliminated? If**
 848 **so, how?**

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858 **A5 What is the necessity of your approach / pro-**
 859 **posed solution/s?**

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869 **A5.1 What will be the limits of applicability of your proposed so-**
 870 **lution/s?**

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880 **A5.2 What will be the message of the proposed solution to**
 881 **technical people? How about to non-technical managers**
 882 **and business men?**

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892 **A6 How will you know if your proposed solution/s**
 893 **is/are correct?**

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903 **A6.1 Will your results warrant the level of mathematics used
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914 **A7 Is/are there an/_ alternative way/s to get to the
 915 same solution/s?**

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925 **A7.1 Can you come up with illustrating examples, or even bet-
 926 ter, counter examples to your proposed solution/s?**

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A7.2 Is there an approximation that can arrive at the essentially the same proposed solution/s more easily?

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 943 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
 944 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 945 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 946 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

A8 If you were the examiner of your proposal, how would you present the proposal in another way?

949 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 950 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
 951 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
 952 placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor.
 953 Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla
 954 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
 955 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 956 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 957 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

A8.1 What are the weaknesses of your proposal?

959 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 960 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
 961 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
 962 placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor.



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- 963 Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla
964 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
965 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
966 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
967 amet ipsum. Nunc quis urna dictum turpis accumsan semper.



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968

Appendix B USAGE EXAMPLES

969



970 The user is expected to have a working knowledge of L^AT_EX. A good introduction
 971 is in [Oetiker et al., 2014]. Its latest version can be accessed at <http://www.ctan.org/tex-archive/info/lshort>.
 972

973 **B1 Equations**

974 The following examples show how to typeset equations in L^AT_EX. This section also shows
 975 examples of the use of `\gls{ }` commands in conjunction with the items that are in
 976 the `notation.tex` file. **Please make sure that the entries in `notation.tex` are**
 977 **those that are referenced in the L^AT_EX document files used by this Thesis. Please**
 978 **comment out unused notations and be careful with the commas and brackets in**
 979 `notation.tex` .

980 In (B.1), the output signal $y(t)$ is the result of the convolution of the input signal $x(t)$
 981 and the impulse response $h(t)$.

$$y(t) = h(t) * x(t) = \int_{-\infty}^{+\infty} h(t - \tau) x(\tau) d\tau \quad (\text{B.1})$$

982 Other example equations are as follows.

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix} \quad (\text{B.2})$$

$$\frac{1}{2} < \left\lfloor \mod \left(\left\lfloor \frac{y}{17} \right\rfloor 2^{-17\lfloor x \rfloor - \mod(\lfloor y \rfloor, 17)}, 2 \right) \right\rfloor, \quad (\text{B.3})$$

$$|\zeta(x)^3 \zeta(x+iy)^4 \zeta(x+2iy)| = \exp \sum_{n,p} \frac{3 + 4 \cos(ny \log p) + \cos(2ny \log p)}{np^{nx}} \geq 1 \quad (\text{B.4})$$



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983 The verbatim L^AT_EX code of Sec. B1 is in List. B.1.

Listing B.1: Sample L^AT_EX code for equations and notations usage

```

1 The following examples show how to typeset equations in \LaTeX.
2
3 In \eqref{eq:conv}, the output signal  $\text{gls}\{not:output_sigt\}$  is the
4 result of the convolution of the input signal  $\text{gls}\{not:input_sigt\}$ 
5 and the impulse response  $\text{gls}\{not:ir\}$ .
6
7 \begin{eqnarray}
8 y\left( t \right) = h\left( t \right) * x\left( t \right) = \int_{-\infty}^{+\infty} h\left( t - \tau \right) x\left( \tau \right) d\tau
9 \end{eqnarray}
10 Other example equations are as follows.
11
12 \begin{eqnarray}
13 \left[ \frac{V_1}{I_1} \right] = \\
14 \begin{bmatrix} A & B \\ C & D \end{bmatrix} \\
15 \left[ \frac{V_2}{I_2} \right] \\
16 \end{eqnarray}
17 \label{eq:ABCD}
18 \end{eqnarray}
19
20 \end{eqnarray}
21
22 \begin{eqnarray}
23 \frac{1}{2} < \left\lfloor \frac{\text{mod}}{\left\lfloor y \right\rfloor} \right\rfloor \left( \left\lfloor \frac{y}{17} \right\rfloor \right. \\
24 \left. \left\lfloor 2^{-17} \left\lfloor x \right\rfloor - \text{mod} \left( \left\lfloor y \right\rfloor, 17 \right), 2 \right) \right)
25 \end{eqnarray}
26
27 \begin{eqnarray}
28 | \zeta(x)^3 \zeta(x+iy)^4 \zeta(x+2iy) | = \\
29 \exp \sum_{n,p} \frac{3+4 \cos(ny \log p) + \cos(2ny \log p)}{np^{nx}} n^{ge 1}
30 \end{eqnarray}

```



984 B2 Notations

985 In order to use the standardized notation, the user is highly suggested to see the ISO 80000-2
 986 standard [ISO, 2009]. The following were taken from `isomath-test.tex`.

987 Math alphabets

988 If there are other symbols in place of Greek letters in a math alphabet, it uses T1 or OT1
 989 font encoding instead of OML.

mathnormal	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9$
mathit	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, ff, fi, \beta, ^!, v, w, 0, 1, 9$
mathrm	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, ff, fi, \beta, ^!, v, w, 0, 1, 9$
mathbf	$\mathbf{A}, \mathbf{B}, \mathbf{\Gamma}, \mathbf{\Delta}, \mathbf{\Theta}, \mathbf{\Lambda}, \mathbf{\Xi}, \mathbf{\Pi}, \mathbf{\Sigma}, \mathbf{\Phi}, \mathbf{\Psi}, \mathbf{\Omega}, ff, fi, \mathbf{\beta}, ^!, \mathbf{v}, \mathbf{w}, 0, 1, 9$
mathsf	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, ff, fi, \mathsf{\beta}, ^!, v, w, 0, 1, 9$
mathtt	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \uparrow, \downarrow, \mathbb{B}, ^!, v, w, 0, 1, 9$

990 New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-italic.

mathbfit	$\mathbf{A}, \mathbf{B}, \mathbf{\Gamma}, \mathbf{\Delta}, \mathbf{\Theta}, \mathbf{\Lambda}, \mathbf{\Xi}, \mathbf{\Pi}, \mathbf{\Sigma}, \mathbf{\Phi}, \mathbf{\Psi}, \mathbf{\Omega}, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9$
mathsfit	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9$
mathsfbf	$\mathbf{A}, \mathbf{B}, \mathbf{\Gamma}, \mathbf{\Delta}, \mathbf{\Theta}, \mathbf{\Lambda}, \mathbf{\Xi}, \mathbf{\Pi}, \mathbf{\Sigma}, \mathbf{\Phi}, \mathbf{\Psi}, \mathbf{\Omega}, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9$

991 Do the math alphabets match?

992 $ax\alpha\omega ax\alpha\omega ax\alpha\omega \quad TC\Theta\Gamma TC\Theta\Gamma TC\Theta\Gamma$

993 Vector symbols

994 Alphabetic symbols for vectors are boldface italic, $\lambda = e_1 \cdot a$, while numeric ones (e.g.
 995 the zero vector) are bold upright, $a + 0 = a$.

996 Matrix symbols

997 Symbols for matrices are boldface italic, too:¹ $\Lambda = E \cdot A$.

¹However, matrix symbols are usually capital letters whereas vectors are small ones. Exceptions are physical quantities like the force vector F or the electrical field E .



998

Tensor symbols

999

Symbols for tensors are sans-serif bold italic,

$$\boldsymbol{\alpha} = \mathbf{e} \cdot \mathbf{a} \iff \alpha_{ijl} = e_{ijk} \cdot a_{kl}.$$

1000

The permittivity tensor describes the coupling of electric field and displacement:

$$\mathbf{D} = \epsilon_0 \epsilon_r \mathbf{E}$$



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	Bold math version
1001	
1002	The “bold” math version is selected with the commands <code>\boldmath</code> or <code>\mathversion{bold}</code>
	mathnormal $A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9$
	mathit $A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, ff, fi, \beta, ^, !, v, w, 0, 1, 9$
	mathrm $A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, ff, fi, \beta, ^, !, v, w, 0, 1, 9$
	mathbf $A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, ff, fi, \beta, ^, !, v, w, 0, 1, 9$
	mathsf $A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, ff, fi, \beta, ^, !, v, w, 0, 1, 9$
	mathtt $A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, ff, fi, \beta, ^, !, v, w, 0, 1, 9$
1003	New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-italic.
	mathbfit $A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9$
	mathsfit $A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9$
	mathsfbfit $A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9$
1004	Do the math alphabets match?
1005	$ax\alpha\omega ax\alpha\omega ax\alpha\omega \quad TC\Theta\Gamma TC\Theta\Gamma TC\Theta\Gamma$
1006	Vector symbols
1007	Alphabetic symbols for vectors are boldface italic, $\lambda = e_1 \cdot a$, while numeric ones (e.g.
1008	the zero vector) are bold upright, $a + 0 = a$.
1009	Matrix symbols
1010	Symbols for matrices are boldface italic, too: ² $\Lambda = E \cdot A$.
1011	Tensor symbols
1012	Symbols for tensors are sans-serif bold italic,
	$\alpha = e \cdot a \iff \alpha_{ijl} = e_{ijk} \cdot a_{kl}.$
1013	The permittivity tensor describes the coupling of electric field and displacement:
	$D = \epsilon_0 \epsilon_r E$
1014	<hr/> <p>²However, matrix symbols are usually capital letters whereas vectors are small ones. Exceptions are physical quantities like the force vector F or the electrical field E.</p>



1015 The verbatim L^AT_EX code of Sec. B2 is in List. B.2.

Listing B.2: Sample L^AT_EX code for notations usage

```

1016   1 % A teststring with Latin and Greek letters::
1017   2 \newcommand{\teststring}{%
1018   3 % capital Latin letters
1019   4 % A,B,C,
1020   5 A,B,
1021
1022   6 % capital Greek letters
1023   7 \%Gamma,\Delta,\Theta,\Lambda,\Xi,\Pi,\Sigma,\Upsilon,\Phi,\Psi,
1024   8 \Gamma,\Delta,\Theta,\Lambda,\Xi,\Pi,\Sigma,\Upsilon,\Phi,\Psi,\Omega,
1025   9 % small Greek letters
1026  10 \alpha,\beta,\pi,\nu,\omega,
1027  11 % small Latin letters:
1028  12 % compare \nu, \omega, v, and w
1029  13 v,w,
1030  14 % digits
1031  15 0,1,9
1032  16 }
1033
1034
1035 19 \subsection*{Math alphabets}
1036
1037 21 If there are other symbols in place of Greek letters in a math
1038 22 alphabet, it uses T1 or OT1 font encoding instead of OML.
1039
1040 24 \begin{eqnarray*}
1041 25 \mbox{\rm \textnormal} & & \teststring \\
1042 26 \mbox{\rm \textit} & & \mathit{\teststring} \\
1043 27 \mbox{\rm \textbf} & & \mathbf{\teststring} \\
1044 28 \mbox{\rm \textsf} & & \mathbf{\teststring} \\
1045 29 \mbox{\rm \textsf} & & \mathsf{\teststring} \\
1046 30 \mbox{\rm \texttt} & & \mathtt{\teststring}
1047 31 \end{eqnarray*}
1048 32 New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-
1049 33 italic.
1050
1051 34 \begin{eqnarray*}
1052 35 \mathbf{\textnormal} & & \mathbf{\teststring} \\
1053 36 \mathbf{\textsf} & & \mathbf{\teststring} \\
1054 37 \mathbf{\texttt} & & \mathbf{\teststring}
1055 38 %
1056 39 Do the math alphabets match?
1057
1058 41 $
1059 42 \mathnormal {a x \alpha \omega}
1060 43 \mathbf{fit} {a x \alpha \omega}
1061 44 \mathbf{\textsf{fit}}{a x \alpha \omega}
1062 45 \quad
1063 46 \mathbf{\textsf{fit}}{T C \Theta \Gamma}
1064 47 \mathbf{fit} {T C \Theta \Gamma}
1065 48 \mathnormal {T C \Theta \Gamma}
1066 49 $
1067 50
1068 51 \subsection*{Vector symbols}
1069 52

```



```

1070      53 Alphabetic symbols for vectors are boldface italic,
1071      54  $\vec{\lambda} = \vec{e}_1 \cdot \vec{a}$ ,
1072      55 while numeric ones (e.g. the zero vector) are bold upright,
1073      56  $\vec{a} + \vec{0} = \vec{a}$ .
1074      57
1075      58 \subsection*{Matrix symbols}
1076      59
1077      60 Symbols for matrices are boldface italic, too: %
1078      61 \footnote{However, matrix symbols are usually capital letters whereas
1079      62 vectors
1080      63 are small ones. Exceptions are physical quantities like the force
1081      64 vector  $\vec{F}$  or the electrical field  $\vec{E}$ .%}
1082      65  $\mathbf{\Lambda} = \mathbf{E} \cdot \mathbf{A}$ .
1083      66
1084      67
1085      68 \subsection*{Tensor symbols}
1086      69
1087      70 Symbols for tensors are sans-serif bold italic,
1088      71
1089      72 \[
1090      73   \alpha = e \cdot \alpha
1091      74   \quad \Longleftarrow \quad
1092      75   \alpha_{ijl} = e_{ijk} \cdot a_{kl}.
1093      76 \]
1094      77
1095      78
1096      79 The permittivity tensor describes the coupling of electric field and
1097      80 displacement: \[
1098      81 \vec{D} = \epsilon_0 \cdot \epsilon_r \cdot \vec{E} \]
1099      82
1100      83
1101      84
1102      85 \newpage
1103      86 \subsection*{Bold math version}
1104      87
1105      88 The ‘‘bold’’ math version is selected with the commands
1106      89 \verb+\boldmath+ or \verb+\mathversion{bold}+
1107      90
1108      91 {\boldmath
1109      92   \begin{eqnarray*}
1110      93     \mathnormal & & \mathit \\ 
1111      94     \mathit & & \mathit{\teststring} \\
1112      95     \mathrm & & \mathrm{\teststring} \\
1113      96     \mathbf & & \mathbf{\teststring} \\
1114      97     \mathsf & & \mathsf{\teststring} \\
1115      98     \mathtt & & \mathtt{\teststring} \\
1116      99   \end{eqnarray*}
1117      100   New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-
1118      101   italic.
1119      102   \begin{eqnarray*}
1120      103     \mathbf{\teststring} & & \mathbf{\teststring} \\
1121      104     \mathsf{\teststring} & & \mathsf{\teststring} \\
1122      105     \mathtt{\teststring} & & \mathtt{\teststring} \\
1123      106   \end{eqnarray*}
1124      107   %
1125      108   Do the math alphabets match?

```



```

1127 108
1128 109 $ 
1129 110 \mathnormal {a x \alpha \omega}
1130 111 \mathbf{f} \mathit{it}{\{a x \alpha \omega\}}
1131 112 \mathsf{fb}{\it{fit}}{\{a x \alpha \omega\}}
1132 113 \quad
1133 114 \mathsf{fb}{\it{fit}}{\{T C \Theta \Gamma\}}
1134 115 \mathbf{f} \mathit{it}{\{T C \Theta \Gamma\}}
1135 116 \mathnormal {T C \Theta \Gamma}
1136 117 $
1137 118
1138 119 \subsection*{Vector symbols}
1139 120
1140 121 Alphabetic symbols for vectors are boldface italic,
1141 122 $ \vec{\lambda} = \vec{e}_1 \cdot \vec{a} $,
1142 123 while numeric ones (e.g. the zero vector) are bold upright,
1143 124 $ \vec{a} + \vec{0} = \vec{a} $.
1144 125
1145 126
1146 127
1147 128
1148 129 \subsection*{Matrix symbols}
1149 130
1150 131 Symbols for matrices are boldface italic, too:%
1151 132 \footnote{However, matrix symbols are usually capital letters whereas
1152 133 vectors
1153 134 are small ones. Exceptions are physical quantities like the force
1154 135 vector $ \vec{F} $ or the electrical field $ \vec{E} $.%}
1155 136 $ \mathbf{matrixsym}{\Lambda} = \mathbf{matrixsym}{E} \cdot \mathbf{matrixsym}{A} . $%
1156 137
1157 138
1158 139 \subsection*{Tensor symbols}
1159 140
1160 141 Symbols for tensors are sans-serif bold italic,
1161 142
1162 143 \[
1163 144 \mathbf{tensorsym}{\alpha} = \mathbf{tensorsym}{e} \cdot \mathbf{tensorsym}{a}
1164 145 \quad \Longleftarrow \quad
1165 146 \alpha_{ijl} = e_{ijk} \cdot a_{kl}.
1166 147 \]
1167 148
1168 149 The permittivity tensor describes the coupling of electric field and
1169 150 displacement: \[
1170 151 \vec{D} = \epsilon_0 \mathbf{tensorsym}{\epsilon}(\mathbf{r}) \vec{E} \]
1171 152 \}
1172 153
1173 154

```



1174 B3 Abbreviation

1175 This section shows examples of the use of L^AT_EX commands in conjunction with the
 1176 items that are in the abbreviation.tex and in the glossary.tex files. Please
 1177 see List. B.3. **To lessen the L^AT_EX compilation time, it is suggested that you use**
 1178 **\acr{ } only for the first occurrence of the word to be abbreviated.**

1179 Again please see List. B.3. Here is an example of first use: alternating current (ac).
 1180 Next use: ac. Full: alternating current (ac). Here's an acronym referenced using \acr :
 1181 hyper-text markup language (html). And here it is again: html. If you are used to the
 1182 glossaries package, note the difference in using \gls : hyper-text markup language
 1183 (html). And again (no difference): hyper-text markup language (html). Here are some more
 1184 entries:

- 1186 • extensible markup language (xml) and cascading style sheet (css).
- 1187 • Next use: xml and css.
- 1188 • Full form: extensible markup language (xml) and cascading style sheet (css).
- 1189 • Reset again.
- 1190 • Start with a capital. Hyper-text markup language (html).
- 1191 • Next: Html. Full: Hyper-text markup language (html).
- 1192 • Prefer capitals? Extensible markup language (XML). Next: XML. Full: extensible
 1193 markup language (XML).
- 1194 • Prefer small-caps? Cascading style sheet (css). Next: CSS. Full: cascading style
 1195 sheet (CSS).
- 1196 • Resetting all acronyms.
- 1197 • Here are the acronyms again:
- 1198 • Hyper-text markup language (HTML), extensible markup language (XML) and cas-
 1199 cading style sheet (CSS).
- 1200 • Next use: HTML, XML and CSS.
- 1201 • Full form: Hyper-text markup language (HTML), extensible markup language (XML)
 1202 and cascading style sheet (CSS).



- 1203 • Provide your own link text: style sheet.

1204 The verbatim L^AT_EX code of Sec. B3 is in List. B.3.

Listing B.3: Sample L^AT_EX code for abbreviations usage

```

1 Again please see List.~\ref{lst:abbrv}. Here is an example of first use:
  \acr{ac}. Next use: \acr{ac}. Full: \gls{ac}. Here's an acronym
  referenced using \verb|\acr|: \acr{html}. And here it is again: \acr{html}.
  If you are used to the \texttt{glossaries} package, note
  the difference in using \verb|\gls|: \gls{html}. And again (no
  difference): \gls{html}. Here are some more entries:
2
3 \begin{itemize}
4
5   \item \acr{xml} and \acr{css}.
6
7   \item Next use: \acr{xml} and \acr{css}.
8
9   \item Full form: \gls{xml} and \gls{css}.
10
11  \item Reset again. \glsresetall{abbreviation}
12
13  \item Start with a capital. \Acr{html}.
14
15  \item Next: \Acr{html}. Full: \Gls{html}.
16
17  \item Prefer capitals? \renewcommand{\acronymfont}[1]{\
      \MakeTextUppercase{#1}} \Acr{xml}. Next: \acr{xml}. Full: \gls{xml}
      }.
18
19  \item Prefer small-caps? \renewcommand{\acronymfont}[1]{\textsc{#1}} \
      \Acr{css}. Next: \acr{css}. Full: \gls{css}.
20
21  \item Resetting all acronyms.\glsresetall{abbreviation}
22
23  \item Here are the acronyms again:
24
25  \item \Acr{html}, \acr{xml} and \acr{css}.
26
27  \item Next use: \Acr{html}, \acr{xml} and \acr{css}.
28
29  \item Full form: \Gls{html}, \gls{xml} and \gls{css}.
30
31  \item Provide your own link text: \glslink{[textbf]css}{style}
32
33 \end{itemize}
```



1205 B4 Glossary

1206 This section shows examples of the use of `\gls{ }` commands in conjunction with the
 1207 items that are in the `glossary.tex` and `notation.tex` files. Note that entries in
 1208 `notation.tex` are prefixed with “`not:`” label (see List. B.4).

1209 **Please make sure that the entries in `notation.tex` are those that are referenced
 1210 in the L^AT_EX document files used by this Thesis. Please comment out unused notations
 1211 and be careful with the commas and brackets in `notation.tex`.**

- 1212 • Matrices are usually denoted by a bold capital letter, such as \mathbf{A} . The matrix’s (i,j) th
 1213 element is usually denoted a_{ij} . Matrix \mathbf{I} is the identity matrix.
- 1214 • A set, denoted as \mathcal{S} , is a collection of objects.
- 1215 • The universal set, denoted as \mathcal{U} , is the set of everything.
- 1216 • The empty set, denoted as \emptyset , contains no elements.
- 1217 • The cardinality of a set, denoted as $|\mathcal{S}|$, is the number of elements in the set.

1218 The verbatim L^AT_EX code for the part of Sec. B4 is in List. B.4.

Listing B.4: Sample L^AT_EX code for glossary and notations usage

```

1 \begin{itemize}
2
3   \item \Glspl{matrix} are usually denoted by a bold capital letter,
4       such as $\mathbf{A}$. The \gls{matrix}'s $(i,j)$th element is
5       usually denoted $a_{ij}$. \Gls{matrix} $\mathbf{I}$ is the
6       identity \gls{matrix}.
7
8   \item A set, denoted as \gls{not:set}, is a collection of objects.
9
10  \item The universal set, denoted as \gls{not:universalSet}, is the
11      set of everything.
12
13  \item The empty set, denoted as \gls{not:emptySet}, contains no
14      elements.
15
16  \item The cardinality of a set, denoted as \gls{not:cardinality}, is
17      the number of elements in the set.
18
19 \end{enumerate}

```



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1219

B5 Figure

1220
1221

This section shows several ways of placing figures. PDFL^AT_EX compatible files are PDF, PNG, and JPG. Please see the `figure` subdirectory.

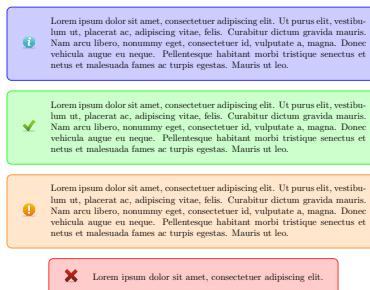


Fig. B.1 A quadrilateral image example.



1222 Fig. B.1 is a gray box enclosed by a dark border. List. B.5 shows the corresponding
1223 L^AT_EX code.

Listing B.5: Sample L^AT_EX code for a single figure

```
1 \begin{figure}[!htbp]
2     \centering
3     \includegraphics[width=0.5\textwidth]{example}
4     \caption{A quadrilateral image example.}
5     \label{fig:example}
6 \end{figure}
7 \cleardoublepage
8
9 Fig.~\ref{fig:example} is a gray box enclosed by a dark border. List.~\ref{lst:onefig} shows the corresponding \LaTeX \ code.
10 \end{figure}
```

B. Usage Examples



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Ut puma sit, consectetur adipiscing elit. Ut puma sit, vestibulum in placerat ac, adipiscing vitas, folia. Curabitur dictum gravida mattis. Nam arcu libero, nonummy est, consectetur id, vulputate a, magna. Donec velit aliquet erat, nonummy, nonummy. Pellentesque habitant morbi tristique semper et netus et malesuada fames ac turpis egestas. Mauris ut leo.

Ut puma sit, consectetur adipiscing elit. Ut puma sit, vestibulum in placerat ac, adipiscing vitas, folia. Curabitur dictum gravida mattis. Nam arcu libero, nonummy est, consectetur id, vulputate a, magna. Donec velit aliquet erat, nonummy, nonummy. Pellentesque habitant morbi tristique semper et netus et malesuada fames ac turpis egestas. Mauris ut leo.

Ut puma sit, consectetur adipiscing elit. Ut puma sit, vestibulum in placerat ac, adipiscing vitas, folia. Curabitur dictum gravida mattis. Nam arcu libero, nonummy est, consectetur id, vulputate a, magna. Donec velit aliquet erat, nonummy, nonummy. Pellentesque habitant morbi tristique semper et netus et malesuada fames ac turpis egestas. Mauris ut leo.

✗ Ut puma sit, consectetur adipiscing elit.

(a) A sub-figure in the top row.

Ut puma sit, consectetur adipiscing elit. Ut puma sit, vestibulum in placerat ac, adipiscing vitas, folia. Curabitur dictum gravida mattis. Nam arcu libero, nonummy est, consectetur id, vulputate a, magna. Donec velit aliquet erat, nonummy, nonummy. Pellentesque habitant morbi tristique semper et netus et malesuada fames ac turpis egestas. Mauris ut leo.

Ut puma sit, consectetur adipiscing elit. Ut puma sit, vestibulum in placerat ac, adipiscing vitas, folia. Curabitur dictum gravida mattis. Nam arcu libero, nonummy est, consectetur id, vulputate a, magna. Donec velit aliquet erat, nonummy, nonummy. Pellentesque habitant morbi tristique semper et netus et malesuada fames ac turpis egestas. Mauris ut leo.

Ut puma sit, consectetur adipiscing elit. Ut puma sit, vestibulum in placerat ac, adipiscing vitas, folia. Curabitur dictum gravida mattis. Nam arcu libero, nonummy est, consectetur id, vulputate a, magna. Donec velit aliquet erat, nonummy, nonummy. Pellentesque habitant morbi tristique semper et netus et malesuada fames ac turpis egestas. Mauris ut leo.

✗ Ut puma sit, consectetur adipiscing elit.

(b) A sub-figure in the middle row.

Ut puma sit, consectetur adipiscing elit. Ut puma sit, vestibulum in placerat ac, adipiscing vitas, folia. Curabitur dictum gravida mattis. Nam arcu libero, nonummy est, consectetur id, vulputate a, magna. Donec velit aliquet erat, nonummy, nonummy. Pellentesque habitant morbi tristique semper et netus et malesuada fames ac turpis egestas. Mauris ut leo.

Ut puma sit, consectetur adipiscing elit. Ut puma sit, vestibulum in placerat ac, adipiscing vitas, folia. Curabitur dictum gravida mattis. Nam arcu libero, nonummy est, consectetur id, vulputate a, magna. Donec velit aliquet erat, nonummy, nonummy. Pellentesque habitant morbi tristique semper et netus et malesuada fames ac turpis egestas. Mauris ut leo.

✗ Ut puma sit, consectetur adipiscing elit.

(c) A sub-figure in the bottom row.

Listing B.6: Sample L^AT_EX code for three figures on top of each other

```
1 \begin{figure} [!htbp]
2   \centering
3   \subbottom[A sub-figure in the top row.]{%
4     \includegraphics [width=0.35\textwidth]{example}
5     \label{fig:top}
6   }
7   \vfill
8   \subbottom[A sub-figure in the middle row.]{%
9     \includegraphics [width=0.35\textwidth]{example}
10    \label{fig:mid}
11  }
12  \vfill
13  \subbottom[A sub-figure in the bottom row.]{%
14    \includegraphics [width=0.35\textwidth]{example}
15    \label{fig:botm}
16  }
17  \caption{Figures on top of each other}
18  \label{fig:tmb}
19 \end{figure}
```

B. Usage Examples



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Lorem ipsum dolor sit amet, consectetur adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consetetur id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo.

✓ Lorem ipsum dolor sit amet, consectetur adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consetetur id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo.

ⓘ Lorem ipsum dolor sit amet, consectetur adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consetetur id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo.

✗ Lorem ipsum dolor sit amet, consectetur adipiscing elit.

ⓘ Lorem ipsum dolor sit amet, consectetur adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consetetur id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo.

✓ Lorem ipsum dolor sit amet, consectetur adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consetetur id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo.

ⓘ Lorem ipsum dolor sit amet, consectetur adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consetetur id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo.

✗ Lorem ipsum dolor sit amet, consectetur adipiscing elit.

(a) A sub-figure in the upper-left corner.

(b) A sub-figure in the upper-right corner.

ⓘ Lorem ipsum dolor sit amet, consectetur adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consetetur id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo.

✓ Lorem ipsum dolor sit amet, consectetur adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consetetur id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo.

ⓘ Lorem ipsum dolor sit amet, consectetur adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consetetur id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo.

✗ Lorem ipsum dolor sit amet, consectetur adipiscing elit.

ⓘ Lorem ipsum dolor sit amet, consectetur adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consetetur id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo.

✓ Lorem ipsum dolor sit amet, consectetur adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consetetur id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo.

ⓘ Lorem ipsum dolor sit amet, consectetur adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consetetur id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo.

✗ Lorem ipsum dolor sit amet, consectetur adipiscing elit.

(c) A sub-figure in the lower-left corner.

(d) A sub-figure in the lower-right corner

Fig. B.3 Four figures in each corner. See List. B.7 for the corresponding L^AT_EX code.

Listing B.7: Sample L^AT_EX code for the four figures

```

1 \begin{figure} [!htbp]
2 \centering
3 \subbottom[A sub-figure in the upper-left corner.]{
4 \includegraphics [width=0.45\textwidth]{example}
5 \label{fig:upprleft}
6 }
7 \hfill
8 \subbottom[A sub-figure in the upper-right corner.]{
9 \includegraphics [width=0.45\textwidth]{example}
10 \label{fig:uppright}
11 }
12 \vfill
13 \subbottom[A sub-figure in the lower-left corner.]{
14 \includegraphics [width=0.45\textwidth]{example}
15 \label{fig:lowerleft}
16 }
17 \hfill
18 \subbottom[A sub-figure in the lower-right corner.]{
19 \includegraphics [width=0.45\textwidth]{example}
20 \label{fig:lowright}
21 }
22 \caption{Four figures in each corner. See List.~\ref{lst:fourfigs} for
the corresponding \LaTeX \ code.}
23 \label{fig:fourfig}
24 \end{figure}

```



1224

B6 Table

1225

This section shows an example of placing a table (a long one). Table B.1 are the triples.

TABLE B.1 FEASIBLE TRIPLES FOR HIGHLY VARIABLE GRID

Time (s)	Triple chosen	Other feasible triples
0	(1, 11, 13725)	(1, 12, 10980), (1, 13, 8235), (2, 2, 0), (3, 1, 0)
2745	(1, 12, 10980)	(1, 13, 8235), (2, 2, 0), (2, 3, 0), (3, 1, 0)
5490	(1, 12, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
8235	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
10980	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
13725	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
16470	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
19215	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
21960	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
24705	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
27450	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
30195	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
32940	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
35685	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
38430	(1, 13, 10980)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
41175	(1, 12, 13725)	(1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
43920	(1, 13, 10980)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
46665	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
49410	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
52155	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
54900	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
57645	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
60390	(1, 12, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
63135	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
65880	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
68625	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
71370	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
74115	(1, 12, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
76860	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
79605	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
82350	(1, 12, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
85095	(1, 12, 13725)	(1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
87840	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
90585	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
93330	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
96075	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
98820	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
101565	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
104310	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
107055	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
109800	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
112545	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
115290	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
118035	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
120780	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
123525	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)

Continued on next page



Continued from previous page

Time (s)	Triple chosen	Other feasible triples
126270	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
129015	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
131760	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
134505	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
137250	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
139995	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
142740	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
145485	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
148230	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
150975	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
153720	(1, 12, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
156465	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
159210	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
161955	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
164700	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)



1227 List. B.8 shows the corresponding L^AT_EX code.

Listing B.8: Sample L^AT_EX code for making typical table environment

```

1228 1 \begin{center}
1229 2 {\scriptsize
1230 3 \begin{tabularx}{\textwidth}{p{0.1\textwidth}|p{0.2\textwidth}|p{0.5\textwidth}}
1231 4 \caption{Feasible triples for highly variable grid} \label{tab:triple_
1232 5 \hline
1233 6 \hline
1234 7 \textbf{Time (s)} &
1235 8 \textbf{Triple chosen} &
1236 9 \textbf{Other feasible triples} \\
1237 10 \hline
1238 11 \endfirsthead
1239 12 \multicolumn{3}{c}{\textit{Continued from previous page}}} \\
1240 13 \hline
1241 14 \hline
1242 15 \hline
1243 16 \textbf{Time (s)} &
1244 17 \textbf{Triple chosen} &
1245 18 \textbf{Other feasible triples} \\
1246 19 \hline
1247 20 \endhead
1248 21 \hline
1249 22 \multicolumn{3}{r}{\textit{Continued on next page}}} \\
1250 23 \endfoot
1251 24 \hline
1252 25 \endlastfoot
1253 26 \hline
1254 27
1255 28 0 & (1, 11, 13725) & (1, 12, 10980), (1, 13, 8235), (2, 2, 0), (3, 1, 0)
1256 29 \\
1257 30 2745 & (1, 12, 10980) & (1, 13, 8235), (2, 2, 0), (2, 3, 0), (3, 1, 0)
1258 31 \\
1259 32 5490 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1260 33 8235 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1,
1261 34 0) \\
1262 35 10980 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1,
1263 36 0) \\
1264 37 13725 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1,
1265 38 0) \\
1266 39 16470 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1267 40 19215 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1,
1268 41 0) \\
1269 42 21960 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1,
1270 43 0) \\
1271 44 24705 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1,
1272 45 0) \\
1273 46 27450 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1,
1274 47 0) \\
1275 48 30195 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1276 49 32940 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1277 50 35685 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1278 51 38430 & (1, 13, 10980) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1279 52
1280 53
1281 54

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1282 43 | 41175 & (1, 12, 13725) & (1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1,
1283   0) \\
1284 44 | 43920 & (1, 13, 10980) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1285 45 | 46665 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1286 46 | 49410 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1287 47 | 52155 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1,
1288   0) \\
1289 48 | 54900 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1290 49 | 57645 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1291 50 | 60390 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1292 51 | 63135 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1293 52 | 65880 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1294 53 | 68625 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1295 54 | 71370 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1296 55 | 74115 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1297 56 | 76860 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1298 57 | 79605 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1299 58 | 82350 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1300 59 | 85095 & (1, 12, 13725) & (1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1,
1301   0) \\
1302 60 | 87840 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1303 61 | 90585 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1304 62 | 93330 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1305 63 | 96075 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1306 64 | 98820 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1307 65 | 101565 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1308 66 | 104310 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1309 67 | 107055 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1310 68 | 109800 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1311 69 | 112545 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
1312   1, 0) \\
1313 70 | 115290 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1314 71 | 118035 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1315 72 | 120780 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1316 73 | 123525 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1317 74 | 126270 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
1318   1, 0) \\
1319 75 | 129015 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1320 76 | 131760 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1321 77 | 134505 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1322 78 | 137250 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1323 79 | 139995 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1324 80 | 142740 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1325 81 | 145485 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
1326   1, 0) \\
1327 82 | 148230 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1328 83 | 150975 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1329 84 | 153720 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1330 85 | 156465 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1331 86 | 159210 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1332 87 | 161955 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1333 88 | 164700 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1334 89 | \end{tabularx} \\
1335 90 | } \\
1336 91 | \end{center}

```



1338

B7 Algorithm or Pseudocode Listing

1339

Table B.2 shows an example pseudocode. Note that if the pseudocode exceeds one page, it can mean that its implementation is not modular. List. B.9 shows the corresponding L^AT_EX code.

1340

1341

TABLE B.2 CALCULATION OF $y = x^n$

Input(s):

n	:	n th power; $n \in \mathbb{Z}^+$
x	:	base value; $x \in \mathbb{R}^+$

Output(s):

y	:	result; $y \in \mathbb{R}^+$
-----	---	------------------------------

Require: $n \geq 0 \vee x \neq 0$
Ensure: $y = x^n$

```

1:  $y \Leftarrow 1$ 
2: if  $n < 0$  then
3:    $X \Leftarrow 1/x$ 
4:    $N \Leftarrow -n$ 
5: else
6:    $X \Leftarrow x$ 
7:    $N \Leftarrow n$ 
8: end if
9: while  $N \neq 0$  do
10:  if  $N$  is even then
11:     $X \Leftarrow X \times X$ 
12:     $N \Leftarrow N/2$ 
13:  else { $N$  is odd}
14:     $y \Leftarrow y \times X$ 
15:     $N \Leftarrow N - 1$ 
16:  end if
17: end while

```

Listing B.9: Sample L^AT_EX code for algorithm or pseudocode listing usage

```

1 \begin{table} [!htbp]
2   \caption{Calculation of $y = x^n$}
3   \label{tab:calcxn}
4   \footnotesize
5   \begin{tabular}{lll}
6     \hline
7     \hline
8     {\bf Input(s):} & & \\
9     $n$ & : & $n$th power; $n \in \mathbb{Z}^{+}$ \\
10    $x$ & : & base value; $x \in \mathbb{R}^{+}$ \\
11    \hline
12    {\bf Output(s):} & & \\
13    $y$ & : & result; $y \in \mathbb{R}^{+}$ \\
14    \hline
15    \hline
16    \\
17  \end{tabular}
18 }
19 \begin{algorithmic}[1]
20 \footnotesize
21   \REQUIRE $n \geq 0 \vee x \neq 0$;
22   \ENSURE $y = x^n$;
23   \STATE $y \Leftarrow 1$;
24   \IF{$n < 0$}
25     \STATE $X \Leftarrow 1 / x$;
26     \STATE $N \Leftarrow -n$;
27   \ELSE
28     \STATE $X \Leftarrow x$;
29     \STATE $N \Leftarrow n$;
30   \ENDIF;
31   \WHILE{$N \neq 0$}
32     \IF{$N$ is even}
33       \STATE $X \Leftarrow X \times X$;
34       \STATE $N \Leftarrow N / 2$;
35     \ELSE[$N$ is odd]
36       \STATE $y \Leftarrow y \times X$;
37       \STATE $N \Leftarrow N - 1$;
38     \ENDIF;
39   \ENDWHILE;
40 }
41 \end{algorithmic}
42 \end{table}

```



1342 B8 Program/Code Listing

1343 List. B.10 is a program listing of a C code for computing Fibonacci numbers by calling the
 1344 actual code. Please see the `code` subdirectory.

Listing B.10: Computing Fibonacci numbers in C (`./code/fibo.c`)

```

1  /* fibo.c -- It prints out the first N Fibonacci
2   *          numbers.
3   */
4
5  #include <stdio.h>
6
7  int main(void) {
8      int n;           /* Number of fibonacci numbers we will print */
9      int i;           /* Index of fibonacci number to be printed next */
10     int current;    /* Value of the (i)th fibonacci number */
11     int next;        /* Value of the (i+1)th fibonacci number */
12     int twoaway;    /* Value of the (i+2)th fibonacci number */
13
14     printf("How\u201duFibonacci\u201dunumbers\u201dudo\u201duyou\u201duwant\u201duto\u201ducompute?\u201du");
15     scanf("%d", &n);
16     if (n<=0)
17         printf("The\u201dunumber\u201dushould\u201dube\u201dupositive.\n");
18     else {
19         printf("\n\n\tI\u201du\tFibonacci(I)\u201du\n\t=====\\n");
20         next = current = 1;
21         for (i=1; i<=n; i++) {
22             printf("\t%d\u201du\t%u\\n", i, current);
23             twoaway = current+next;
24             current = next;
25             next = twoaway;
26         }
27     }
28 }
29
30 /* The output from a run of this program was:
31
32 How many Fibonacci numbers do you want to compute? 9
33
34 I      Fibonacci(I)
35 =====
36 1      1
37 2      1
38 3      2
39 4      3
40 5      5
41 6      8
42 7      13
43 8      21
44 9      34
45
46 */

```



1345

List. B.11 shows the corresponding L^AT_EX code.

Listing B.11: Sample L^AT_EX code for program listing

1 `List.\ref{lst:fib_c}` is a program listing of a C code for computing Fibonacci numbers by calling the actual code. Please see the `\verb|code|` subdirectory.



1346 B9 Referencing

1347 Referencing chapters: This appendix is in Appendix B, which is about examples in using
 1348 various \LaTeX commands.

1349 Referencing sections: This section is Sec. B9, which shows how to refer to the locations
 1350 of various labels that have been placed in the \LaTeX files. List. B.12 shows the corresponding
 1351 \LaTeX code.

Listing B.12: Sample \LaTeX code for referencing sections

1 Referencing sections: This section is Sec.~\ref{sec:ref}, which shows
 how to refer to the locations of various labels that have been
 placed in the \LaTeX \ files. List.~\ref{lst:refsec} shows the
 corresponding \LaTeX \ code.

1352 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1353 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
 1354 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
 1355 placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor.
 1356 Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla
 1357 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
 1358 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1359 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1360 amet ipsum. Nunc quis urna dictum turpis accumsan semper.



B9.1 A subsection

Referencing subsections: This section is Sec. B9.1, which shows how to refer to a subsection. List. B.13 shows the corresponding L^AT_EX code.

Listing B.13: Sample L^AT_EX code for referencing subsections

```
1 Referencing subsections: This section is Sec.\ref{sec:subsec}, which
  shows how to refer to a subsection. List.\ref{lst:refsub} shows the
  corresponding \LaTeX \ code.
```

1364 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1365 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
 1366 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
 1367 placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor.
 1368 Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla
 1369 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
 1370 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1371 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1372 amet ipsum. Nunc quis urna dictum turpis accumsan semper.



1373 B9.1.1 A sub-subsection

1374 Referencing sub-subsections: This section is Sec. B9.1.1, which shows how to refer to a
 1375 sub-subsection. List. B.14 shows the corresponding L^AT_EX code.

Listing B.14: Sample L^AT_EX code for referencing sub-subsections

```
1 Referencing sub-subsections: This section is Sec.~\ref{sec:subsubsec},  

   which shows how to refer to a sub-subsection. List.~\ref{lst:  

   refsubsub} shows the corresponding \LaTeX \ code.
```

1376 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1377 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
 1378 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
 1379 placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor.
 1380 Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla
 1381 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
 1382 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1383 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1384 amet ipsum. Nunc quis urna dictum turpis accumsan semper.



1385 B10 Index

1386 For key words or topics that are expected (or the user would like) to appear in the Index, use
 1387 `index{key}` , where `key` is an example keyword to appear in the Index. For example,
 1388 Fredholm integral and Fourier operator of the following paragraph are in the Index.

1389 If we make a very large matrix with complex exponentials in the rows (i.e., cosine real
 1390 parts and sine imaginary parts), and increase the resolution without bound, we approach
 1391 the kernel of the Fredholm integral equation of the 2nd kind, namely the Fourier operator
 1392 that defines the continuous Fourier transform.

1393 List. B.15 is a program listing of the above-mentioned paragraph.

Listing B.15: Sample L^AT_EX code for Index usage

```
1 If we make a very large matrix with complex exponentials in the rows (i.  

   e., cosine real parts and sine imaginary parts), and increase the  

   resolution without bound, we approach the kernel of the \index{  

   Fredholm integral} Fredholm integral equation of the 2nd kind,  

   namely the \index{Fourier} Fourier operator that defines the  

   continuous Fourier transform.
```



1394 **B11 Adding Relevant PDF Pages (e.g. Standards,**
1395 **Datasheets, Specification Sheets, Application**
1396 **Notes, etc.)**

1397 Selected PDF pages can be added (see List. B.16), but note that the options must be tweaked.
1398 See the manual of `pdfpages` for other options.

Listing B.16: Sample L^AT_EX code for including PDF pages

```
1 \includepdf[pages={8-10},%  
2 offset=3.5mm -10mm,%  
3 scale=0.73,%  
4 frame]  
5 {./reference/Xilinx2015-UltraScaleArchitectureOverview.pdf}
```



Virtex UltraScale FPGA Feature Summary

Table 6: Virtex UltraScale FPGA Feature Summary

	VU065	VU080	VU095	VU125	VU160	VU190	VU440
Logic Cells	626,640	780,000	940,800	1,253,280	1,621,200	1,879,920	4,432,680
CLB Flip-Flops	716,160	891,424	1,075,200	1,432,320	1,852,800	2,148,480	5,065,920
CLB LUTs	358,080	445,712	537,600	716,160	926,400	1,074,240	2,532,960
Maximum Distributed RAM (Mb)	4.8	3.9	4.8	9.7	12.7	14.5	28.7
Block RAM/FIFO w/ECC (36Kb each)	1,260	1,421	1,728	2,520	3,276	3,780	2,520
Total Block RAM (Mb)	44.3	50.0	60.8	88.6	115.2	132.9	88.6
CMT (1 MMCM, 2 PLLs)	10	16	16	20	30	30	30
I/O DLLs	40	64	64	80	120	120	120
Fractional PLLs	5	8	8	10	15	15	0
Maximum HP I/Os ⁽¹⁾	468	780	780	780	650	650	1,404
Maximum HR I/Os ⁽²⁾	52	52	52	104	52	52	52
DSP Slices	600	672	768	1,200	1,560	1,800	2,880
System Monitor	1	1	1	2	3	3	3
PCIe Gen3 x8	2	4	4	4	5	6	6
150G Interlaken	3	6	6	6	8	9	0
100G Ethernet	3	4	4	6	9	9	3
GTH 16.3Gb/s Transceivers	20	32	32	40	52	60	48
GTy 30.5Gb/s Transceivers	20	32	32	40	52	60	0

Notes:

1. HP = High-performance I/O with support for I/O voltage from 1.0V to 1.8V.
2. HR = High-range I/O with support for I/O voltage from 1.2V to 3.3V.



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UltraScale Architecture and Product Overview

Virtex UltraScale Device-Package Combinations and Maximum I/Os

Table 7: Virtex UltraScale Device-Package Combinations and Maximum I/Os

Package ⁽¹⁾⁽²⁾⁽³⁾	Package Dimensions (mm)	VU065	VU080	VU095	VU125	VU160	VU190	VU440
		HR, HP GTH, GTY						
FFVC1517	40x40	52, 468 20, 20	52, 468 20, 20	52, 468 20, 20				
FFVD1517	40x40		52, 286 32, 32	52, 286 32, 32				
FLVD1517	40x40				52, 286 40, 32			
FFVB1760	42.5x42.5		52, 650 32, 16	52, 650 32, 16				
FLVB1760	42.5x42.5				52, 650 36, 16			
FFVA2104	47.5x47.5		52, 780 28, 24	52, 780 28, 24				
FLVA2104	47.5x47.5				52, 780 28, 24			
FFVB2104	47.5x47.5		52, 650 32, 32	52, 650 32, 32				
FLVB2104	47.5x47.5				52, 650 40, 36			
FLGB2104	47.5x47.5					52, 650 40, 36	52, 650 40, 36	
FFVC2104	47.5x47.5			52, 364 32, 32				
FLVC2104	47.5x47.5				52, 364 40, 40			
FLGC2104	47.5x47.5					52, 364 52, 52	52, 364 52, 52	
FLGB2377	50x50							52, 1248 36, 0
FLGA2577	52.5x52.5						0, 448 60, 60	
FLGA2892	55x55							52, 1404 48, 0

Notes:

1. Go to [Ordering Information](#) for package designation details.
2. All packages have 1.0mm ball pitch.
3. Packages with the same last letter and number sequence, e.g., A2104, are footprint compatible with all other UltraScale architecture-based devices with the same sequence. The footprint compatible devices within this family are outlined. See the [UltraScale Architecture Product Selection Guide](#) for details on inter-family migration.



Virtex UltraScale+ FPGA Feature Summary

Table 8: Virtex UltraScale+ FPGA Feature Summary

	VU3P	VU5P	VU7P	VU9P	VU11P	VU13P
Logic Cells	689,640	1,051,010	1,379,280	2,068,920	2,147,040	2,862,720
CLB Flip-Flops	788,160	1,201,154	1,576,320	2,364,480	2,453,760	3,271,680
CLB LUTs	394,080	600,577	788,160	1,182,240	1,226,880	1,635,840
Max. Distributed RAM (Mb)	12.0	18.3	24.1	36.1	34.8	46.4
Block RAM/FIFO w/ECC (36Kb each)	720	1,024	1,440	2,160	2,016	2,688
Block RAM (Mb)	25.3	36.0	50.6	75.9	70.9	94.5
UltraRAM Blocks	320	470	640	960	1,152	1,536
UltraRAM (Mb)	90.0	132.2	180.0	270.0	324.0	432.0
CIMTs (1 MMCM and 2 PLLs)	10	20	20	30	12	16
Max. HP I/O ⁽¹⁾	520	832	832	832	624	832
DSP Slices	2,280	3,474	4,560	6,840	8,928	11,904
System Monitor	1	2	2	3	3	4
GTY Transceivers 32.75Gb/s	40	80	80	120	96	128
PCIe Gen3 x16 and Gen4 x8	2	4	4	6	3	4
150G Interlaken	3	4	6	9	9	12
100G Ethernet w/RS-FEC	3	4	6	9	6	8

Notes:

1. HP = High-performance I/O with support for I/O voltage from 1.0V to 1.8V.

Virtex UltraScale+ Device-Package Combinations and Maximum I/Os

Table 9: Virtex UltraScale+ Device-Package Combinations and Maximum I/Os

Package (1)(2)(3)	Package Dimensions (mm)	VU3P	VU5P	VU7P	VU9P	VU11P	VU13P
		HP, GTY	HP, GTY	HP, GTY	HP, GTY	HP, GTY	HP, GTY
FFVC1517	40x40	520, 40					
FLVF1924	45x45					624, 64	
FLVA2104	47.5x47.5		832, 52	832, 52	832, 52		
FHVA2104	52.5x52.5 ⁽⁴⁾						832, 52
FLVB2104	47.5x47.5		702, 76	702, 76	702, 76	624, 76	
FHVB2104	52.5x52.5 ⁽⁴⁾						702, 76
FLVC2104	47.5x47.5		416, 80	416, 80	416, 104	416, 96	
FHVC2104	52.5x52.5 ⁽⁴⁾						416, 104
FLVA2577	52.5x52.5				448, 120	448, 96	448, 128

Notes:

1. Go to [Ordering Information](#) for package designation details.
2. All packages have 1.0mm ball pitch.
3. Packages with the same last letter and number sequence, e.g., A2104, are footprint compatible with all other UltraScale devices with the same sequence. The footprint compatible devices within this family are outlined.
4. These 52.5x52.5mm overhang packages have the same PCB ball footprint as the corresponding 47.5x47.5mm packages (i.e., the same last letter and number sequence) and are footprint compatible.



1402 **Appendix C**
1403 **PUBLICATION LIST AND AWARD**

1404 **Journal**

1405 1. ...

1406 2. ...

1407 **Conference**

1408 1. ...

1409 2. ...



De La Salle University

1410 **Others**

1411 1. ...

1412 2. ...

1413 **Award**

1414 1. ...

1415 2. ...



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Appendix D VITA

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De La Salle University



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Ervin Lester G. Lu is a third year engineering student taking up B.Sc. Computer Engineering at De La Salle University. He has designed and programmed several applications using C and Java languages, and electronic circuits using Arduino and PIC as microcontrollers in some of his previous projects. His research interests include educational mobile applications, environmental friendly innovations, and agriculture technologies.



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Sean Wyndell T. Que is a third year engineering student taking up B.Sc. Computer Engineering at De La Salle University. He has designed and programmed several electronic circuits using PIC microcontrollers and mobile applications using C and Java languages. His research interests include cool electronic gadgets and awesome mobile applications.



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