[[1]](#footnote-2)

Preparation of Papers for IEEE TRANSACTIONS and JOURNALS(December2013)

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*Abstract*—This paper reports on the recently developed pruning algorithm for the Feed Forward Multi Layer Perceptron. The importance of finding the ideal structure for an artificial neural networks lies in its efficient computations, fast convergence and its ability to generalize for yet unseen data. For that a new approach to pruning a neural network was recently developed and introduced in [1] based on a decorrelation approach between the nodes of the hidden layer. In this paper, that algorithm is applied to six classification problems and three prediction problems. The goal in both cases is to find the optimal hidden layer structure for each of these problems. Finally, we compare the results of our computed structure to the accuracies reported in some of the recent literature.

*Index Terms*—Artificial Intelligence, Machine Learning, Neural Networks, Pruning.

# INTRODUCTION

A

rtificial neural networks are a paradigm of biologically inspired learning used in a wide range of machine learning applications. Ever since the conception of the Multi Layer Perceptron, artificial neural networks have been at the forefront of the research efforts in the field of learning systems and intelligent agents. In this paper, we discuss one of the main problems of using a Multi Layer Preceptron, choosing a structure. The significance of this problem is apparent from the sheer number of algorithms and heuristics that have been developed in order to address it. However despite these efforts there is yet to be a concrete solution, that can satisfactorily guarantee an optimal or a near optimal structure. Here we report on the performance of a recently developed algorithm that is based on the idea of pruning the network till it reaches its optimal structure [1].

# THE PROBLEM

A standard Multi Layer Preceptron consists of three components: input layer, output layer and a variable number of hidden layers. The number of nodes in the input and output layer is determined by the problem's domain and range respectively. Thus the only variables become the number of hidden layers and the number of nodes in each layer. It has been shown that a single hidden layer is sufficient for most standard problems, leaving only the number of hidden nodes to be determined.

Several heuristics for determining the size of the hidden layer exist based on different tradeoffs. Increasing the size of the hidden layer can lead to faster convergence, however the increase in the number of variables (degrees of freedom) risks over fitting. This can impact the networks ability to generalize for new unseen data. On the other hands reducing the number of hidden nodes can make it hard for the network to converge, increase the error value and reduce output confidence.

Ideally the structure of the MLP should be the smallest structure that can adequately generalize for new data. In practice, however, such structure is hard to determine, mainly due to the lack of semantic connection between the data and the hidden nodes. While we know that the hidden layer is responsible for mapping the input to the desired output, we have no notion of a semantic contribution of a single node to such mapping.

# The Algorithm

This algorithm belongs to a group of algorithms for optimizing artificial neural network structure called pruning algorithms. In a pruning algorithm, the network starts with a large number of hidden nodes, guaranteed to be more than required by the problem. During training, the structure of the network is gradually improved by removing nodes that are determined to be redundant. Training terminates once no more nodes can be removed [1].

## Overview

This algorithm tries to minimize the hidden layers size by reducing the variance of hidden nodes. This maximizes the correlation between the activation of each node and the net output of the network. Intuitively, it can be expected that the nodes whose activation has the least correlation to the output of the network can be removed without greatly impacting the performance of the network.

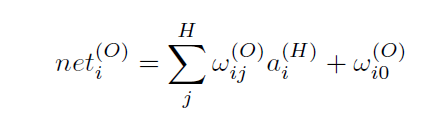
## Network Structure

In order to determine the correlation between the activation of a hidden node and the output of an output node, the variance of hidden layer activations needs to be considered. Thus this algorithm introduces a lateral connection from each hidden node to the following hidden nodes in the same layer. The lateral connections are only fed to the nodes following the origin and not the preceding nodes to keep the network strictly feed forward. 

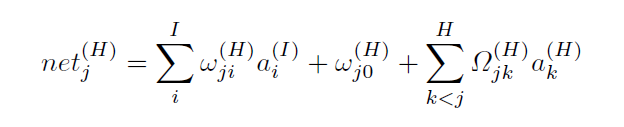
## Training

The nodes of the network are created with a sigmoid activation function for both the hidden nodes and the output nodes. The rules for the forward network propagation - taken from [1] - are as follows:

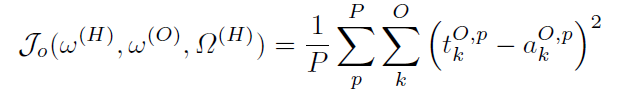
Net input for the hidden nodes

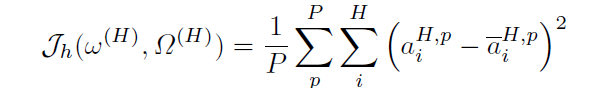


Net input for the output nodes

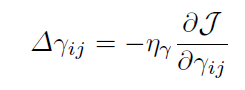


In order to train the network, we calculate an error function with

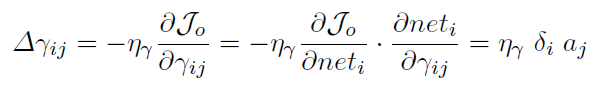




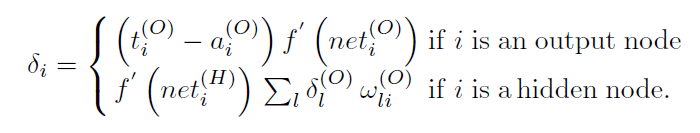
To find the minimum of the error function we approximate gradient descent using the stochastic approach. For each feature vector in the dataset we update the network weights to minimize the error function Jo using the following update rules:



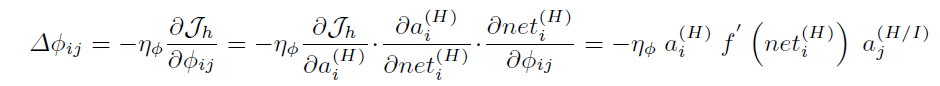
Where Δγij is calculated using the back propagation algorithm with



where η is the learning rate and δ is calculated from



For minimizing the Jh error function, we use the following update rule



# Results

Use either SI (MKS) or CGS as primary units. (SI units are strongly encouraged.) English units may be used as secondary units (in parentheses). This applies to papers in data storage**.** For example, write “15 Gb/cm2 (100 Gb/in2).” An exception is when English units are used as identifiers in trade, such as “3½-in disk drive.” Avoid combining SI and CGS units, such as current in amperes and magnetic field in oersteds. This often leads to confusion because equations do not balance dimensionally. If you must use mixed units, clearly state the units for each quantity in an equation.

The SI unit for magnetic field strength *H* is A/m. However, if you wish to use units of T, either refer to magnetic flux density *B* or magnetic field strength symbolized as µ0*H*. Use the center dot to separate compound units, e.g., “A·m2.”

# Some Common Mistakes

The word “data” is plural, not singular. The subscript for the permeability of vacuum µ0 is zero, not a lowercase letter “o.” The term for residual magnetization is “remanence”; the adjective is “remanent”; do not write “remnance” or “remnant.” Use the word “micrometer” instead of “micron.” A graph within a graph is an “inset,” not an “insert.” The word “alternatively” is preferred to the word “alternately” (unless you really mean something that alternates). Use the word “whereas” instead of “while” (unless you are referring to simultaneous events). Do not use the word “essentially” to mean “approximately” or “effectively.” Do not use the word “issue” as a euphemism for “problem.” When compositions are not specified, separate chemical symbols by en-dashes; for example, “NiMn” indicates the intermetallic compound Ni0.5Mn0.5 whereas “Ni–Mn” indicates an alloy of some composition NixMn1-x.

Be aware of the different meanings of the homophones “affect” (usually a verb) and “effect” (usually a noun), “complement” and “compliment,” “discreet” and “discrete,” “principal” (e.g., “principal investigator”) and “principle” (e.g., “principle of measurement”). Do not confuse “imply” and “infer.”

Prefixes such as “non,” “sub,” “micro,” “multi,” and “ultra” are not independent words; they should be joined to the words they modify, usually without a hyphen. There is no period after the “et” in the Latin abbreviation “*et al.*” (it is also italicized). The abbreviation “i.e.,” means “that is,” and the abbreviation “e.g.,” means “for example” (these abbreviations are not italicized).

A general IEEE styleguide is available at <http://www.ieee.org/web/publications/authors/transjnl/index.html>



Fig. 1.Magnetization as a function of applied field. Note that “Fig.” is abbreviated. There is a period after the figure number, followed by two spaces. It is good practice to explain the significance of the figure in the caption.

TABLE I

Units for Magnetic Properties

|  |  |  |
| --- | --- | --- |
| Symbol | Quantity | Conversion from Gaussian and  CGS EMU to SI a |
| Φ | magnetic flux | 1 Mx→ 10−8Wb = 10−8 V·s |
| *B* | magnetic flux density,  magnetic induction | 1 G → 10−4 T = 10−4Wb/m2 |
| *H* | magnetic field strength | 1 Oe→ 103/(4π) A/m |
| *m* | magnetic moment | 1 erg/G = 1 emu  → 10−3 A·m2 = 10−3 J/T |
| *M* | magnetization | 1 erg/(G·cm3) = 1 emu/cm3  → 103 A/m |
| 4π*M* | magnetization | 1 G → 103/(4π) A/m |
| σ | specific magnetization | 1 erg/(G·g) = 1 emu/g → 1 A·m2/kg |
| *j* | magnetic dipole  moment | 1 erg/G = 1 emu  → 4π× 10−10Wb·m |
| *J* | magnetic polarization | 1 erg/(G·cm3) = 1 emu/cm3  → 4π× 10−4 T |
| χ*,*κ | susceptibility | 1 → 4π |
| χρ | mass susceptibility | 1 cm3/g → 4π× 10−3 m3/kg |
| μ | permeability | 1 → 4π× 10−7 H/m  = 4π× 10−7Wb/(A·m) |
| μr | relative permeability | μ→μr |
| *w, W* | energy density | 1 erg/cm3→ 10−1 J/m3 |
| *N, D* | demagnetizing factor | 1 → 1/(4π) |

Vertical lines are optional in tables. Statements that serve as captions for the entire table do not need footnote letters.

aGaussian units are the same as cg emu for magnetostatics; Mx = maxwell, G = gauss, Oe = oersted; Wb = weber, V = volt, s = second, T = tesla, m = meter, A = ampere, J = joule, kg = kilogram, H = henry.

# Guidelines for Graphics Preparation and Submission

## Types of Graphics

The following list outlines the different types of graphics published in IEEE journals. They are categorized based on their construction, and use of color / shades of gray:

### *Color/Grayscale figures*

### Figures that are meant to appear in color, or shades of black/gray. Such figures may include photographs, illustrations, multicolor graphs, and flowcharts.

### *Lineart figures*

### Figures that are composed of only black lines and shapes. These figures should have no shades or half-tones of gray. Only black and white.

### *Author photos*

### Head and shoulders shots of authors which appear at the end of our papers.

### *Tables* Data charts which are typically black and white, but sometimes include color.

## Multipart figures

Figures compiled of more than one sub-figure presented side-by-side, or stacked. If a multipart figure is made up of multiple figure types (one part is lineart, and another is grayscale or color) the figure should meet the stricter guidelines.

## File Formats For Graphics

Format and save your graphics using a suitable graphics processing program that will allow you to create the images as PostScript (PS), Encapsulated PostScript (.EPS), Tagged Image File Format (.TIFF), Portable Document Format (.PDF), or Portable Network Graphics (.PNG) sizes them, and adjusts the resolution settings. If you created your source files in one of the following programs you will be able to submit the graphics without converting to a PS, EPS, TIFF, PDF, or PNG file: Microsoft Word, Microsoft PowerPoint, or Microsoft Excel. Though it is not required, it is recommended that these files be saved in PDF format rather than DOC, XLS, or PPT. Doing so will protect your figures from common font and arrow stroke issues that occur when working on the files across multiple platforms. When submitting your final paper, your graphics should all be submitted individually in one of these formats along with the manuscript.

## Sizing of Graphics

Most charts, graphs, and tables are one column wide (3.5 inches / 88 millimeters / 21 picas) or page wide (7.16 inches / 181 millimeters / 43 picas). The maximum depth a graphic can be is 8.5 inches (216 millimeters / 54 picas). When choosing the depth of a graphic, please allow space for a caption. Figures can be sized between column and page widths if the author chooses, however it is recommended that figures are not sized less than column width unless when necessary.

There is currently one publication with column measurements that don’t coincide with those listed above. Proceedings of the IEEE has a column measurement of 3.25 inches (82.5 millimeters / 19.5 picas).

The final printed size of author photographs is exactly   
1 inch wide by 1.25 inches tall (25.4millimeters x 31.75 millimeters / 6 picas x 7.5 picas). Author photos printed in editorials measure 1.59 inches wide by 2 inches tall (40 millimeters x 50 millimeters / 9.5 picas x 12 picas).

## Resolution

The proper resolution of your figures will depend on the type of figure it is as defined in the “Types of Figures” section. Author photographs, color, and grayscale figures should be at least 300dpi. Lineart, including tables should be a minimum of 600dpi.

## Vector Art

While IEEE does accept, and even recommends that authors submit artwork in vector format, it is our policy is to rasterize all figures for publication. This is done in order to preserve the figures’ integrity across multiple computer platforms.

## Color Space

The term color space refers to the entire sum of colors that can be represented within the said medium. For our purposes, the three main color spaces are Grayscale, RGB (red/green/blue) and CMYK (cyan/magenta/yellow/black). RGB is generally used with on-screen graphics, whereas CMYK is used for printing purposes.

All color figures should be generated in RGB or CMYK color space. Grayscale images should be submitted in Grayscale color space. Line art may be provided in grayscale OR bitmap colorspace. Note that “bitmap colorspace” and “bitmap file format” are not the same thing. When bitmap color space is selected, .TIF/.TIFF is the recommended file format.

## Accepted Fonts Within Figures

When preparing your graphics IEEE suggests that you use of one of the following Open Type fonts: Times New Roman, Helvetica, Arial, Cambria, and Symbol. If you are supplying EPS, PS, or PDF files all fonts must be embedded. Some fonts may only be native to your operating system; without the fonts embedded, parts of the graphic may be distorted or missing.

A safe option when finalizing your figures is to strip out the fonts before you save the files, creating “outline” type. This converts fonts to artwork what will appear uniformly on any screen.

## Using Labels Within Figures

### Figure Axis labels

Figure axis labels are often a source of confusion. Use words rather than symbols. As an example, write the quantity “Magnetization,” or “Magnetization *M*,” not just “*M*.” Put units in parentheses. Do not label axes only with units. As in Fig. 1, for example, write “Magnetization (A/m)” or “Magnetization (Am−1),” not just “A/m.” Do not label axes with a ratio of quantities and units. For example, write “Temperature (K),” not “Temperature/K.”

Multipliers can be especially confusing. Write “Magnetization (kA/m)” or “Magnetization (103 A/m).” Do not write “Magnetization (A/m) × 1000” because the reader would not know whether the top axis label in Fig. 1 meant 16000 A/m or 0.016 A/m. Figure labels should be legible, approximately 8 to 10 point type.

### Subfigure Labels in Multipart Figures and Tables

Multipart figures should be combined and labeled before final submission. Labels should appear centered below each subfigure in 8 point Times New Roman font in the format of (a) (b) (c).

## File Naming

Figures (line artwork or photographs) should be named starting with the first 5 letters of the author’s last name. The next characters in the filename should be the number that represents the sequential location of this image in your article. For example, in author “Anderson’s” paper, the first three figures would be named ander1.tif, ander2.tif, and ander3.ps.

Tables should contain only the body of the table (not the caption) and should be named similarly to figures, except that ‘.t’ is inserted in-between the author’s name and the table number. For example, author Anderson’s first three tables would be named ander.t1.tif, ander.t2.ps, ander.t3.eps.

Author photographs should be named using the first five characters of the pictured author’s last name. For example, four author photographs for a paper may be named: oppen.ps, moshc.tif, chen.eps, and duran.pdf.

If two authors or more have the same last name, their first initial(s) can be substituted for the fifth, fourth, third... letters of their surname until the degree where there is differentiation. For example, two authors Michael and Monica Oppenheimer’s photos would be namedoppmi.tif, and oppmo.eps.

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When referencing your figures and tables within your paper, use the abbreviation “Fig.” even at the beginning of a sentence. Do not abbreviate “Table.” Tables should be numbered with Roman Numerals.

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you do not need to position figures and tables at the top and bottom of each column. In fact, all figures, figure captions, and tables can be placed at the end of your paper. In addition to, or even in lieu of submitting figures within your final manuscript, figures should be submitted individually, separate from the manuscript in one of the file formats listed above in section VI-J. Place figure captions below the figures; place table titles above the tables. Please do not include captions as part of the figures, or put them in “text boxes” linked to the figures. Also, do not place borders around the outside of your figures.

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## A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

Appendix

Appendixes, if needed, appear before the acknowledgment.

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The preferred spelling of the word “acknowledgment” in American English is without an “e” after the “g.” Use the singular heading even if you have many acknowledgments. Avoid expressions such as “One of us (S.B.A.) would like to thank ... .” Instead, write “F. A. Author thanks ... .”In most cases, sponsor and financial support acknowledgments are placed in the unnumbered footnote on the first page, not here.

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References need not be cited in text. When they are, number citations on the line, in square brackets inside the punctuation. Multiple references are each numbered with separate brackets. When citing a section in a book, please give the relevant page numbers. In text, refer simply to the reference number. Do not use “Ref.” or “reference” except at the beginning of a sentence: “Reference [3] shows ... .” Please do not use automatic endnotes in *Word*, rather, type the reference list at the end of the paper using the “References” style.

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## Footnotes

Number footnotes separately in superscripts (Insert | Footnote).[[2]](#footnote-3) Place the actual footnote at the bottom of the column in which it is cited; do not put footnotes in the reference list (endnotes). Use letters for table footnotes (see Table I).

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If you want to submit your file with one column electronically, please do the following:

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--Third, click and drag the right margin bar to just over 4 inches in width.

The graphics will stay in the “second” column, but you can drag them to the first column. Make the graphic wider to push out any text that may try to fill in next to the graphic.

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References

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1. J. K. Author, “Title of chapter in the book,” in *Title of His Published Book, x*th ed. City of Publisher, Country if not
2. USA: Abbrev. of Publisher, year, ch.*x*, sec. *x*, pp. *xxx–xxx.*

*Examples:*

1. G.O.Young,“Syntheticstructureofindustrial plastics,”in *Plastics,* 2nded., vol. 3, J. Peters, Ed. New York: McGraw-Hill,1964,pp.15–64.
2. W.-K.Chen,*LinearNetworksandSystems.*Belmont, CA:Wadsworth, 1993, pp. 123–135.

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1. J. K. Author, “Name of paper,” *Abbrev. Title of Periodical*, vol. *x,* no. *x,* pp*. xxx-xxx,* Abbrev. Month, year.

*Examples:*

1. J. U. Duncombe, “Infrared navigation—Part I: An assessment   
   of feasibility,” *IEEE Trans. Electron Devices*, vol. ED-11, no. 1, pp. 34–39, Jan. 1959.
2. E. P. Wigner, “Theory of traveling-wave optical laser,”*Phys. Rev*.,   
   vol. 134, pp. A635–A646, Dec. 1965.
3. E. H. Miller, “A note on reflector arrays,” *IEEE Trans.Antennas Propagat*., to be published.

*Basic format for reports:*

1. J. K. Author, “Title of report,” Abbrev. Name of Co., City of Co., Abbrev. State, Rep. *xxx*, year.

*Examples:*

1. E. E. Reber, R. L. Michell, and C. J. Carter, “Oxygen absorption in the earth’s atmosphere,” Aerospace Corp., LosAngeles, CA, Tech. Rep. TR-0200 (4230-46)-3, Nov. 1988.
2. J. H. Davis and J. R. Cogdell, “Calibration program for the 16-foot antenna,” Elect. Eng. Res. Lab., Univ. Texas, Austin, Tech. Memo. NGL-006-69-3, Nov. 15, 1987.

*Basic format for handbooks:*

1. *Name of Manual/Handbook*, *x* ed., Abbrev. Name of Co., City of Co., Abbrev. State, year, pp. *xxx-xxx.*

*Examples:*

1. *Transmission Systems for Communications*, 3rd ed., Western Electric Co., Winston-Salem, NC, 1985, pp. 44–60.
2. *Motorola Semiconductor Data Manual*, Motorola Semiconductor Products Inc., Phoenix, AZ, 1989.

*Basic format for books (when available online):*

1. Author.(year,monthday).*Title.*(edition)[Typeofmedium].*volume (issue).*Available: site/path/file

*Example:*

1. J. Jones.(1991, May 10). *Networks.*(2nded.)[Online]. Available:[http://www.atm.com](http://www.atm.com/)

*Basic format for journals (when available online):*

1. Author. (year, month). Title.*Journal.*[Typeof medium].*volume (issue),* pages. Available: site/path/file

*Example:*

1. R. J. Vidmar. (1992, Aug.). On the use of atmospheric plasmasaselectromagneticreflectors. *IEEETrans. PlasmaSci.*[Online].*21(3),*pp. 876–880. Available:<http://www.halcyon.com/pub/journals/21ps03-vidmar>

*Basic format for paperspresented at conferences (when available online):*

1. Author. (year,month). Title. Presented at Conference title. [Type of Medium]. Available: site/path/file

*Example:*

1. PROCESS Corp., MA. Intranets: Internet technologies deployedbehindthefirewall forcorporateproductivity. Presentedat  
   INET96AnnualMeeting.[Online].Available:<http://home.process.com/Intranets/wp2.htp>

*Basic format for reports and handbooks (when available online):*

1. Author. (year, month). Title. Company.City,StateorCountry.[TypeofMedium].Available: site/path/file

*Example:*

1. S. L. Talleen. (1996,Apr.). The Intranet Archi-tecture: Managinginformation in the new paradigm.AmdahlCorp., CA. [Online]. Available:<http://www.amdahl.com/doc/products/bsg/intra/infra/html>

*Basic format for computerprograms andelectronicdocuments(when available online):*ISOrecommendsthatcapitalizationfollowtheacceptedpracticefor thelanguage orscript in whichtheinformation isgiven.

*Example:*

1. A.Harriman.(1993,June).Compendiumofgenealogicalsoftware. *Humanist.*[Online].Availablee-mail: [HUMANIST@NYVM.ORG](mailto:HUMANIST@NYVM.ORG)Message: getGENEALOGY REPORT

*Basic format for patents (when available online):*

1. Name of the invention, by inventor’s name. (year, month day). *Patent Number* [Type of medium]. Available:site/path/file

*Example:*

1. Musical toothbrush with adjustable neck and mirror, by L.M.R. Brooks. (1992, May 19). *Patent D 326 189*

[Online]. Available: NEXIS Library: LEXPAT File: DESIGN

*Basic format for conference proceedings (published):*

1. J. K. Author, “Title of paper,” in *Abbreviated Name of Conf.*, City of Conf., Abbrev. State (if given), year, pp. *xxxxxx.*

*Example:*

1. D. B. Payne and J. R. Stern, “Wavelength-switched pas- sivelycoupledsingle-mode opticalnetwork,”in *Proc. IOOC-ECOC,*1985,  
   pp.585–590.

*Example for paperspresentedat conferences(unpublished):*

1. D.EbehardandE.Voges,“Digitalsinglesidebanddetectionforinterferometricsensors,”presentedat the2ndInt. Conf.OpticalFiberSensors,Stuttgart,Germany,Jan.2-5, 1984.

*Basic formatfor patents:*

1. J. K. Author, “Title of patent,” U.S. Patent *x xxx xxx*, Abbrev. Month, day, year.

*Example:*

1. G. Brandli and M. Dick, “Alternatingcurrent fed power supply,”  
   U.S.Patent 4 084 217,Nov.4,1978.

*Basic formatfor theses (M.S.) and dissertations (Ph.D.):*

1. J. K. Author, “Title of thesis,” M.S. thesis, Abbrev. Dept., Abbrev. Univ., City of Univ., Abbrev. State, year.
2. J. K. Author, “Title of dissertation,” Ph.D. dissertation, Abbrev. Dept., Abbrev. Univ., City of Univ., Abbrev. State,year.

*Examples:*

1. J. O. Williams, “Narrow-band analyzer,” Ph.D. dissertation, Dept. Elect. Eng., Harvard Univ., Cambridge, MA,1993.
2. N. Kawasaki, “Parametric study of thermal and chemical nonequilibrium nozzle flow,” M.S. thesis, Dept. Electron.Eng., Osaka Univ., Osaka, Japan, 1993.

*Basic format for the most common types of unpublished references:*

1. J. K. Author, private communication, Abbrev. Month, year.
2. J. K. Author, “Title of paper,” unpublished.
3. J. K. Author, “Title of paper,” to be published.

*Examples:*

1. A. Harrison, private communication, May 1995.
2. B. Smith, “An approach to graphs of linear forms,” unpublished.
3. A. Brahms, “Representation error for real numbers in binary computer arithmetic,” IEEE Computer GroupRepository, Paper R-67-85.

*Basic format for standards:*

1. *Title of Standard*, Standard number, date.

*Examples:*

1. IEEE Criteria for Class IE Electric Systems, IEEE Standard 308, 1969.
2. Letter Symbols for Quantities, ANSI Standard Y10.5-1968.

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The second paragraph uses the pronoun of the person (he or she) and not the author’s last name. It lists military and work experience, including summer and fellowship jobs. Job titles are capitalized. The current job must have a location; previous positions may be listed without one. Information concerning previous publications may be included. Try not to list more than three books or published articles. The format for listing publishers of a book within the biography is: title of book (city, state: publisher name, year) similar to a reference. Current and previous research interests end the paragraph.

The third paragraph begins with the author’s title and last name (e.g., Dr. Smith, Prof. Jones, Mr. Kajor, Ms. Hunter). List any memberships in professional societies other than the IEEE. Finally, list any awards and work for IEEE committees and publications. If a photograph is provided, the biography will be indented around it. The photograph is placed at the top left of the biography, and should be of good quality, professional-looking, and black and white (see above example). Personal hobbies will be deleted from the biography. Following are two examples of an author’s biography.

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1. [↑](#footnote-ref-2)
2. It is recommended that footnotes be avoided (except for the unnumbered footnote with the receipt date on the first page). Instead, try to integrate the footnote information into the text. [↑](#footnote-ref-3)