Point-process based representation learning for Electronic Health Records

Hojjat Karami, *Fellow, IEEE*, Anisoara Ionescu, and David Atienza, *Member, IEEE*

***Abstract*— It is very well accepted that missingness in electronic health records (EHRs) are not at random which is regarded as informative missingness. The clinician's decision on when to observe lab tests over time can be modeled using point processes. We propose a novel framework based on neural point process to analyze laboratory tests of ICU patients. This framework can take into account additional information for better characterization of conditional intensity function (CIF) as well as better accuracy in prediction of future timestamp and labels.**

***Index Terms*— Enter keywords or phrases in alphabetical order, separated by commas. For a list of suggested keywords, send a blank e-mail to keywords@ieee.org or visit the site.**

I. Introduction

Writing an effective abstract is an indispensable part of any form of research, since it that can motivate the audience to read follow the rest of the text. In this task, I have analyzed five abstracts from the field of artificial intelligence (AI). The table in section 2 shows a summary of the most important aspects of the analyzed abstracts.

II. Background

Temporal point process

Neural temporal point process

Handling irregular sampling

III. Related Works

IV. Proposed Model

The entire data consists of N samples $\mathcal{D} = \{\mathcal{O}_i = (\mathcal{E}_i, \mathcal{S}_i)\}_{i=1}^{N}$ where $\mathcal{E}_i$ and $\mathcal{S}_i$ represents event and state sequences, respectively.

Each event sequnce consist of L tuples $\mathcal{E}_i = \{(t_j, e_j)\}_{j=1}^{L_i}$ where $t_j \in \mathbb{R}$ is the event timestamp and e_j is the event mark.

This paragraph of the first footnote will contain the date on which you submitted your paper for review. It will also contain support information, including sponsor and financial support acknowledgment. For example, "This work was supported in part by the U.S. Department of Commerce under Grant BS123456."

The next few paragraphs should contain the authors' current affiliations, including current address and e-mail. For example, F. A. Author is with the National Institute of Standards and Technology, Boulder, CO 80305 USA (e-mail: author@boulder.nist.gov).

S. B. Author, Jr., was with Rice University, Houston, TX 77005 USA. He is now with the Department of Physics, Colorado State University, Fort Collins, CO 80523 USA (e-mail: author@lamar.colostate.edu).

T. C. Author is with the Electrical Engineering Department, University of Colorado, Boulder, CO 80309 USA, on leave from the National Research Institute for Metals, Tsukuba, Japan (e-mail: author@nrim.go.jp).

Event sequence data consists of N sequences $\{\mathcal{S}_i\}_{i=1}^{N}$, where each sequence $\mathcal{S}_i$ is a series of L_i events $\{(t_j, e_j)\}_{j=1}^{L_i}$. Here, e_j represents events that could be independent our mutually exclusive occurring at t_i.

In addition to the event data, we might have additional information $\{\mathcal{D}_i\}_{i=1}^{N}$. Suppose that each state is represented as $\{(t_k, v_k, m_k)\}_{k=1}^{P_i}$, consisting of a time value $t_k \in \mathbb{R}^+$, an observed value $z_k \in \mathbb{R}$ and a modality indicator $m_k \in \{1, ..., M\}$.

General schematic of TEDAM is depicted in FIG which consists of two separate module: Transformer Event Encoder (TEE) and Deep Attention Module (DAM). TEE encodes timestamp and mark of events using a transformer architecture, while DAM encodes all available information using one-dimensional attention mechanism. Finally, the learned representations are concatenated to be optimized for different loss functions.

A. Event Encoder

We use a similar transformer architecture [thp] for encoding events with minor modifications. A transformer architecture is capable of .

let . that can be embedded using a trainable embedding matrix.

In the first step, we embed all event marks $E_{emb} = E \times U$ where $E_i \in [L, K]$ is the binary encoding matrix of all event marks (multi-label or multi-class), and $W_{emb} \in \mathbb{R}^{K \times d_{emb}}$ is the trainable embedding matrix. In the second step, timestamps should be encoded and added to the event embedding, however, we propose to concatenate time encodings that can lead to better characterization of conditional intensity functions. Finally, the input of the transformer encoder will be $x_{emb} = [y(k_j), z(t_j)]$.

Here, we use the standard transformer encoder similar to [vaswani] with masking matrix to prevent the model from looking into the future. we obtain the encoded matrix $H = (h_1, ..., h_j, ..., h_L)$ where h_j containes the all available information before occurence of $j - th$ event.

B. bin of Event Encoder

it is necessary to include temporal information. Similar to the original positional encoding [vaswani], we use a temporal encoding procedure:

$$[z(t_j)]_k = \begin{cases} \sin\left(\frac{t_j}{\mathcal{T}^{(k-1)/d_t}}\right) & \text{if } k \text{ is odd} \\ \sin\left(\frac{t_j}{\mathcal{T}^{k/d_t}}\right) & \text{if } k \text{ is even} \end{cases} \tag{1}$$

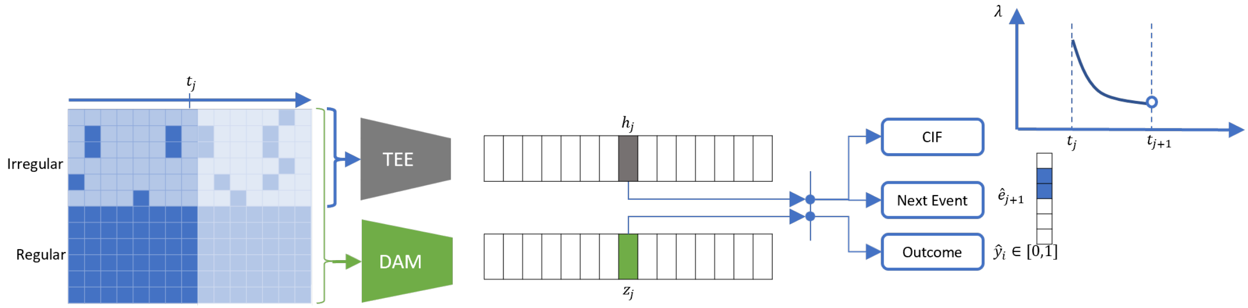

Fig. 1. Magnetization as a function of applied field. It is good practice to explain the significance of the figure in the caption.

Here, $d_t \in \mathbb{N}$ is the dimensionality of encoded timestamp and $z \in \mathbb{R}^{d_t}$ is the embeding vector of timestamp.

Each event mark e_j is projected to a sparse binary vector representation. We add an embedding layer to achieve a more compact and efficient representation emb. Here, w and b are weights and biases of the embedding layer which can be learned during network training.

While previous works suggested adding temporal encoding to the embedded events, we propose to concatenate these two vectors. The effectiveness of this concatenation is further investigated in the results.

$$x_{emb} = [y(k_j), z(t_j)] \tag{2}$$

Now that the x_{emb} is ready for encoding, it is encoded through a standard transformer encoder with multiple layers and attention heads.

$$x_{enc} = TE(x_{emb}) \tag{3}$$

C. State Encoder

Here, we propose a method to incorporate additional information for a better representation. In healthcare, much data is available from different modalities such as vital signs and laboratory values.

Similar to [setF], we use an attention-based aggregation approach for encoding all additional information. Each side information (t_k, v_k, m_k) can be represented by $s_k = (z(t_k), v_k, m_k)$. we define attention $a(\mathcal{S}_k, s_k)$

We define $\mathcal{S}_p$ to be the set of the first p available information. The goal is to calculate $a(\mathcal{S}_p, s_k), k \leq p$ that is the relevance of k-th observation s_k to the first p observed values $\mathcal{S}_p$. This is achieved by computing an embedding of the set elements using a smaller set functions f', and projecting the concatenation of the set representation and the individual set element into d-dimensional space:

$$f'(\mathcal{S}_p) = g'\left(\frac{1}{p}\sum_{s_k \in \mathcal{S}_p} h'_\theta(s_k)\right)$$
$$K_p = [f'(\mathcal{S}_p), s_p]^T W^K$$

Furthermore, we define a query vector $w^q \in \mathbb{R}^d$, which allows the model to summarize different aspects of the dataset via

$$e_p = \frac{K_p.w^q}{\sqrt{d}}$$

Now, the desired attention can be computed as follows:

$$a(\mathcal{S}_p, s_k) = \frac{\exp(e_p)}{\sum_{k \leq p} \exp(e_k)}$$

Finally, we compute a weighted aggregation of set elements:

$$f(\mathcal{S}_p) = g_\psi\left(\sum_{s_k \in \mathcal{S}_p} a(\mathcal{S}_p, s_k) h_\theta(s_k)\right)$$

Without loss of generality, we can consider multiple heads by adding an additional dimension to keys and queries.

All formulas are:

$$\begin{cases} f'(\mathcal{S}_p) = g'\left(\frac{1}{p}\sum_{s_k \in \mathcal{S}_p} h'_\theta(s_k)\right) \\ K_p = [f'(\mathcal{S}_p), s_p]^T W^K \\ e_p = \frac{K_p.w^q}{\sqrt{d}} \\ a(\mathcal{S}_p, s_k) = \frac{\exp(e_p)}{\sum_{k \leq p} \exp(e_k)} \\ f(\mathcal{S}_p) = \sum_{s_k \in \mathcal{S}_p} a(\mathcal{S}_p, s_k) h_\theta(s_k) \\ z_p = g_\psi\left(f(\mathcal{S}_p)\right) \end{cases}$$

D. Mark and Time Decoder

by concatenating encoded events x_{enc} and additional information $f'(\mathcal{S}_p)$, we can predict next marks and times as follows:

$$\hat{e}_{j+1} = MLP([x_j, f'(\mathcal{S}_j)]) \tag{4}$$

$$\hat{t}_{j+1} = MLP([x_j, f'(\mathcal{S}_j)]) \tag{5}$$

$$\mathcal{L}_{mark} = \tag{6}$$

$$\mathcal{L}_{time} = \sum_{j=1}^{L-1} \left((\hat{t}_{j+1} - t_j) - (t_{j+1} - t_j)\right)^2 \tag{7}$$

E. Event Decoder

Once we obtain a representation of a patient using embedded events and states, we can try to parameterize conditional intensity functions (CIFs) of the events.

In neural point process literature, many approaches have been propose to decode either conditional or cumulative intensity function.

$$\lambda_k(t|\mathcal{H}_t) = f_k\left(\alpha_k \frac{t-t_j}{t_j} + \mathbf{w}_k^T \mathbf{x}_{enc}(t_j) + \mathbf{y}_k^T \mathbf{s}_{enc}(t_j) + b_k\right) \tag{8}$$

$$\lambda_k(t|\mathcal{H}_t) = f_k\left(\alpha_k \frac{t-t_j}{t_j} + \mathbf{w}_k^T \mathbf{x}_{enc}(t_j) + b_k\right) \tag{9}$$

V. Experiments

Datasets

Physionet 2019 Sepsis Early Prediction Challenge (*P19*). This dataset contains clinical data of about 40k patients in ICU. Clinical data consist of demographics, vital signs and laboratory values as well as sepsis label in a one-hour time grid. Our objective is to predict the timestamp of next lab sampling events as well as measured variables (event marks) given the patient history.

MIMIC-IV (*M4*). We selected Medical Information Mart for Intensive Care (MIMIC) IV [1], which is a real-world clinical database comprising health data relating to over 40,000 patients admitted to ICU at the Beth Israel Deaconess Medical Center.

Synthea(*Syn*). We used the Synthea simulator (Walonoski et al., 2018) which generates patient-level EHRs using human expert curated Markov processes. Here, we reused the already processed version of this data by Edgauard.

Stackoverflow (*SO*). StackOverflow is a question-answering website. The website rewards users with badges to promote engagement in the community, and the same badge can be rewarded multiple times to the same user. We collect data in a two-year period, and we treat each user's reward history as a sequence. Each event in the sequence signifies receipt of a particular medal.

Scenarios

To investigate the effectiveness of the proposed method, we consider three input scenarios (TE, DA, TE+DA) as well as three loss functions (next event, CIF, next event+CIF) which would result in nine scenarios.

The first series of experiments are conducted to investigate the advantage of encoding additional information for parameterization of intensity functions. We consider seven scenarios: Here, the baseline models

To show the effectiveness of time concatenation we report.

Baselines

we use NEURALTPP that is already developed pipeline by as they already considered a lot of comibinations.

Metrics

We report the weighted AUPRC, AUROC of next predicted event as well as root mean sqaure error (RMSE) of next measurement interval. For evaluating the goodness of fit for the parameterized point process, we report normalized negative likelihood normalized by number of ocurred event (NLL/events). Furthermore, we can also evaluate the learned representation of each patient to predict the sepsis label in a binary classification task.

VI. Results and Discussion

In this section, we present our results regarding the advantage of state and event encoding.

A. Effect of minor improvements

effect of time concatenation
compare single+mark with mc or ml

TABLE I
ADD CAPTION

Dataset	Metric	shp+mark concat	shp+mark sum	baseline
SO	NLL	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
	AUROC	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
	time	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
Synthea	NLL	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
	AUROC	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
	time	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
ReTweet	NLL	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
	AUROC	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
	time	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)

B. Negative Likelihood with state encoding

Table 1 shows the result for estimation of negative likelihood in different datasets and sceanrios. It is obvious that state encoding has led to lower NLL.

TABLE II
ADD CAPTION

Dataset	setting	Model TE	Model TE+DAM	Model TE+noise
P12	sc	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
	mc1	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
	mc2	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
p19	sc	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
	mc1	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
	mc2	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)

can u provide one example patient?

C. Downstream task with event encoding

Another key element of our work is to show the effectiveness of point process modeling for a down-stream task. In Table, we have reported the performance metrics for the mortality prediction task. We have compared our results with several sota's DL models that are compatible with irregular time series.

TABLE III
ADD CAPTION

Dataset	Setting	Center	F1 DAM	F1 TE+DAM	AUPRC DAM	AUPRC TE+DAM	AUROC DAM	AUROC TE+DAM
P12	sc	1	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
		2	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
		3	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
	mc1	1	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
		2	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
		3	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
	mc2	-	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
	seft	-	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
P19	sc	1	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
		2	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
		3	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
	mc1	1	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
		2	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
		3	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
	mc2	-	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)
	seft	-	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)	0.55 (0.02)

D. Learned representions

Fig 1 visualizes the tsne plot for the two scenarios.

E. Model interpretability

one advantage of proposed method is use of attention mechanisms in both event and state encoder. Fig 1 shows the attention mechanism

F. Likelihood estimation

Although CIF does not improve mark prediction, it has led to better representation of patient for downstream task such as sepsis prediction.

In addition, we can interpret some of learned CIF patterns.
explain the effect of time concatenation in SO dataset
tsne of learned representation. 4 modes:

- (DA,TE)-¿(Mark, CIF)

attention of DA for sepsis prediction
attention matrix of events for SO dataset

VII. Conclusion

VIII. Introduction

THIS document is a template for LaTeX. If you are reading a paper or PDF version of this document, please download the electronic file, trans_jour.tex, from the IEEE Web site at http://www.ieee.org/authortools/trans_jour.tex so you can use it to prepare your manuscript. If you would prefer to use LaTeX, download IEEE's LaTeX style and sample files from the same Web page. You can also explore using the Overleaf editor at https://www.overleaf.com/blog/278-how-to-use-overleaf-with-ieee-collabratec-your-quick-guide-to-getting-started#.xsVp6tpPkrKM9

If your paper is intended for a conference, please contact your conference editor concerning acceptable word processor formats for your particular conference.

IEEE will do the final formatting of your paper. If your paper is intended for a conference, please observe the conference page limits.

A. Abbreviations and Acronyms

Define abbreviations and acronyms the first time they are used in the text, even after they have already been defined in the abstract. Abbreviations such as IEEE, SI, ac, and dc do not have to be defined. Abbreviations that incorporate periods should not have spaces: write "C.N.R.S.," not "C. N. R. S." Do not use abbreviations in the title unless they are unavoidable (for example, "IEEE" in the title of this article).

B. Other Recommendations

Use one space after periods and colons. Hyphenate complex modifiers: "zero-field-cooled magnetization." Avoid dangling participles, such as, "Using (10), the potential was calculated." [It is not clear who or what used (10).] Write instead, "The potential was calculated by using (10)," or "Using (10), we calculated the potential."

Use a zero before decimal points: "0.25," not ".25." Use "cm^3," not "cc." Indicate sample dimensions as "0.1 cm $\times$ 0.2 cm," not "0.1 $\times$ 0.2 cm^2." The abbreviation for "seconds" is "s," not "sec." Use "Wb/m^2" or "webers per square meter," not "webers/m^2." When expressing a range of values, write "7 to 9" or "7–9," not "7$\sim$9."

A parenthetical statement at the end of a sentence is punctuated outside of the closing parenthesis (like this). (A parenthetical sentence is punctuated within the parentheses.) In American English, periods and commas are within quotation marks, like "this period." Other punctuation is "outside"! Avoid contractions; for example, write "do not" instead of "don't." The serial comma is preferred: "A, B, and C" instead of "A, B and C."

If you wish, you may write in the first person singular or plural and use the active voice ("I observed that . . ." or

"We observed that ..." instead of "It was observed that ..."). Remember to check spelling. If your native language is not English, please get a native English-speaking colleague to carefully proofread your paper.

Try not to use too many typefaces in the same article. You're writing scholarly papers, not ransom notes. Also please remember that MathJax can't handle really weird typefaces.

C. Equations

Number equations consecutively with equation numbers in parentheses flush with the right margin, as in (10). To make your equations more compact, you may use the solidus (/), the exp function, or appropriate exponents. Use parentheses to avoid ambiguities in denominators. Punctuate equations when they are part of a sentence, as in

$$E = mc^2. \tag{10}$$

Be sure that the symbols in your equation have been defined before the equation appears or immediately following. Italicize symbols (T might refer to temperature, but T is the unit tesla). Refer to "(10)," not "Eq. (10)" or "equation (10)," except at the beginning of a sentence: "Equation (10) is ... ."

D. LaTeX-Specific Advice

Please use "soft" (e.g., `\eqref{Eq}`) cross references instead of "hard" references (e.g., `(1)`). That will make it possible to combine sections, add equations, or change the order of figures or citations without having to go through the file line by line.

Please don't use the `{eqnarray}` equation environment. Use `{align}` or `{IEEEeqnarray}` instead. The `{eqnarray}` environment leaves unsightly spaces around relation symbols.

Please note that the `{subequations}` environment in LaTeX will increment the main equation counter even when there are no equation numbers displayed. If you forget that, you might write an article in which the equation numbers skip from (17) to (20), causing the copy editors to wonder if you've discovered a new method of counting.

BibTeX does not work by magic. It doesn't get the bibliographic data from thin air but from .bib files. If you use BibTeX to produce a bibliography you must send the .bib files.

LaTeX can't read your mind. If you assign the same label to a subsubsection and a table, you might find that Table I has been cross referenced as Table IV-B3.

LaTeX does not have precognitive abilities. If you put a `\label` command before the command that updates the counter it's supposed to be using, the label will pick up the last counter to be cross referenced instead. In particular, a `\label` command should not go before the caption of a figure or a table.

Do not use `\nonumber` inside the `{array}` environment. It will not stop equation numbers inside `{array}` (there won't be any anyway) and it might stop a wanted equation number in the surrounding equation.

If you are submitting your paper to a colorized journal, you can use the following two lines at the start of the article to ensure its appearance resembles the final copy:

```
\documentclass[journal,twoside,web]{ieeecolor}
\usepackage{Journal_Name}
```

IX. Units

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/cm^2 (100 Gb/in^2)." 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 $\mu_0 H$. Use the center dot to separate compound units, e.g., "A·m^2."

X. Some Common Mistakes

The word "data" is plural, not singular. The subscript for the permeability of vacuum μ_0 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 $\mathrm{Ni}_{0.5}\mathrm{Mn}_{0.5}$ whereas "Ni–Mn" indicates an alloy of some composition $\mathrm{Ni}_x\mathrm{Mn}_{1-x}$.

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/authortools.

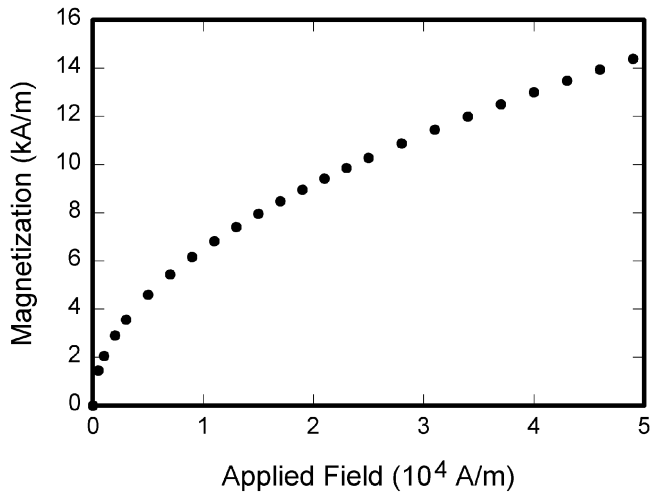

Fig. 2. Magnetization as a function of applied field. It is good practice to explain the significance of the figure in the caption.

XI. Guidelines for Graphics Preparation and Submission

A. 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:

1) 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.

2) Line Art 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.

3) Author photos: Head and shoulders shots of authors that appear at the end of our papers.

4) Tables: Data charts which are typically black and white, but sometimes include color.

B. 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.

C. 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), Portable Network Graphics (.PNG), or Metapost (.MPS), sizes them, and adjusts the resolution settings. When submitting your final paper, your graphics should all be submitted individually in one of these formats along with the manuscript.

TABLE IV
Units for Magnetic Properties

Symbol	Quantity	Conversion from Gaussian and CGS EMU to SI [a]
Φ	magnetic flux	1 Mx $\rightarrow 10^{-8}$ Wb $= 10^{-8}$ V·s
B	magnetic flux density, magnetic induction	1 G $\rightarrow 10^{-4}$ T $= 10^{-4}$ Wb/m^2
H	magnetic field strength	1 Oe $\rightarrow 10^3/(4\pi)$ A/m
m	magnetic moment	1 erg/G $= 1$ emu $\rightarrow 10^{-3}$ A·m^2 $= 10^{-3}$ J/T
M	magnetization	1 erg/(G·cm^3) $= 1$ emu/cm^3 $\rightarrow 10^3$ A/m
$4\pi M$	magnetization	1 G $\rightarrow 10^3/(4\pi)$ A/m
σ	specific magnetization	1 erg/(G·g) $= 1$ emu/g $\rightarrow 1$ A·m^2/kg
j	magnetic dipole moment	1 erg/G $= 1$ emu $\rightarrow 4\pi \times 10^{-10}$ Wb·m
J	magnetic polarization	1 erg/(G·cm^3) $= 1$ emu/cm^3 $\rightarrow 4\pi \times 10^{-4}$ T
χ, κ	susceptibility	$1 \rightarrow 4\pi$
χ_ρ	mass susceptibility	1 cm^3/g $\rightarrow 4\pi \times 10^{-3}$ m^3/kg
μ	permeability	$1 \rightarrow 4\pi \times 10^{-7}$ H/m $= 4\pi \times 10^{-7}$ Wb/(A·m)
μ_r	relative permeability	$\mu \rightarrow \mu_r$
w, W	energy density	1 erg/cm^3 $\rightarrow 10^{-1}$ J/m^3
N, D	demagnetizing factor	$1 \rightarrow 1/(4\pi)$

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

D. 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 do not 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 (25.4 millimeters $\times$ 31.75 millimeters/6 picas $\times$ 7.5 picas). Author photos printed in editorials measure 1.59 inches wide by 2 inches tall (40 millimeters $\times$ 50 millimeters/9.5 picas $\times$ 12 picas).

E. 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. Line art, including tables should be a minimum of 600dpi.

F. Vector Art

In order to preserve the figures' integrity across multiple computer platforms, we accept files in the following formats: .EPS/.PDF/.PS. All fonts must be embedded or text converted to outlines in order to achieve the best-quality results.

G. 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/.PNG are the recommended file formats.

H. 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.

I. Using Labels Within Figures

1) 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 (A$\cdot$m^{-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 (10^3 A/m)." Do not write "Magnetization (A/m) $\times$ 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.

2) 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).

J. 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 named oppmi.tif, and oppmo.eps.

K. Referencing a Figure or Table Within Your Paper

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.

L. Checking Your Figures: The IEEE Graphics Analyzer

The IEEE Graphics Analyzer enables authors to pre-screen their graphics for compliance with IEEE Transactions and Journals standards before submission. The online tool, located at http://graphicsqc.ieee.org/, allows authors to upload their graphics in order to check that each file is the correct file format, resolution, size and colorspace; that no fonts are missing or corrupt; that figures are not compiled in layers or have transparency, and that they are named according to the IEEE Transactions and Journals naming convention. At the end of this automated process, authors are provided with a detailed report on each graphic within the web applet, as well as by email.

For more information on using the Graphics Analyzer or any other graphics related topic, contact the IEEE Graphics Help Desk by e-mail at graphics@ieee.org.

M. Submitting Your Graphics

Because IEEE will do the final formatting of your paper, 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 XI-C. 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.

N. Color Processing/Printing in IEEE Journals

All IEEE Transactions, Journals, and Letters allow an author to publish color figures on IEEE Xplore® at no charge, and automatically convert them to grayscale for print versions. In most journals, figures and tables may alternatively be printed in color if an author chooses to do so. Please note that this service comes at an extra expense to the author. If you intend to have print color graphics, include a note with your final paper indicating which figures or tables you would like to be handled that way, and stating that you are willing to pay the additional fee.

XII. Conclusion

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.

Appendixes, if needed, appear before the acknowledgment.

Acknowledgment

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.

References and Footnotes

A. References

References need not be cited in text. When they are, they appear 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.

Reference numbers are set flush left and form a column of their own, hanging out beyond the body of the reference. The reference numbers are on the line, enclosed in square brackets. In all references, the given name of the author or editor is abbreviated to the initial only and precedes the last name. Use them all; use *et al.* only if names are not given. Use commas around Jr., Sr., and III in names. Abbreviate conference titles. When citing IEEE transactions, provide the issue number, page range, volume number, year, and/or month if available. When referencing a patent, provide the day and the month of issue, or application. References may not include all information; please obtain and include relevant information. Do not combine references. There must be only one reference with each number. If there is a URL included with the print reference, it can be included at the end of the reference.

Other than books, capitalize only the first word in a paper title, except for proper nouns and element symbols. For papers published in translation journals, please give the English citation first, followed by the original foreign-language citation See the end of this document for formats and examples of common references. For a complete discussion of references and their formats, see the IEEE style manual at http://www.ieee.org/authortools.

B. Footnotes

Number footnotes separately in superscript numbers.[1] 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 IV).

Appendix I
Submitting Your Paper for Review

A. Final Stage

When you submit your final version (after your paper has been accepted), print it in two-column format, including figures and tables. You must also send your final manuscript on a disk, via e-mail, or through a Web manuscript submission system as directed by the society contact. You may use *Zip* for large files, or compress files using *Compress, Pkzip, Stuffit,* or *Gzip.*

Also, send a sheet of paper or PDF with complete contact information for all authors. Include full mailing addresses, telephone numbers, fax numbers, and e-mail addresses. This information will be used to send each author a complimentary copy of the journal in which the paper appears. In addition, designate one author as the “corresponding author.” This is the author to whom proofs of the paper will be sent. Proofs are sent to the corresponding author only.

B. Review Stage Using ScholarOne® Manuscripts

Contributions to the Transactions, Journals, and Letters may be submitted electronically on IEEE’s on-line manuscript submission and peer-review system, ScholarOne® Manuscripts. You can get a listing of the publications that participate in ScholarOne at http://www.ieee.org/publications_standards/publications/authors/authors_submission.html. First check if you have an existing account. If there is none, please create a new account. After logging in, go to your Author Center and click “Submit First Draft of a New Manuscript.”

Along with other information, you will be asked to select the subject from a pull-down list. Depending on the journal, there are various steps to the submission process; you must complete all steps for a complete submission. At the end of each step you must click “Save and Continue”; just uploading the paper is not sufficient. After the last step, you should see a confirmation that the submission is complete. You should also receive an e-mail confirmation. For inquiries regarding the submission of your paper on ScholarOne Manuscripts, please contact oprs-support@ieee.org or call +1 732 465 5861.

ScholarOne Manuscripts will accept files for review in various formats. Please check the guidelines of the specific journal for which you plan to submit.

You will be asked to file an electronic copyright form immediately upon completing the submission process (authors are responsible for obtaining any security clearances). Failure to submit the electronic copyright could result in publishing

[1] 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.

delays later. You will also have the opportunity to designate your article as "open access" if you agree to pay the IEEE open access fee.

C. Final Stage Using ScholarOne Manuscripts

Upon acceptance, you will receive an email with specific instructions regarding the submission of your final files. To avoid any delays in publication, please be sure to follow these instructions. Most journals require that final submissions be uploaded through ScholarOne Manuscripts, although some may still accept final submissions via email. Final submissions should include source files of your accepted manuscript, high quality graphic files, and a formatted pdf file. If you have any questions regarding the final submission process, please contact the administrative contact for the journal.

In addition to this, upload a file with complete contact information for all authors. Include full mailing addresses, telephone numbers, fax numbers, and e-mail addresses. Designate the author who submitted the manuscript on ScholarOne Manuscripts as the "corresponding author." This is the only author to whom proofs of the paper will be sent.

D. Copyright Form

Authors must submit an electronic IEEE Copyright Form (eCF) upon submitting their final manuscript files. You can access the eCF system through your manuscript submission system or through the Author Gateway. You are responsible for obtaining any necessary approvals and/or security clearances. For additional information on intellectual property rights, visit the IEEE Intellectual Property Rights department web page at http://www.ieee.org/publications_standards/publications/rights/index.html.

Appendix II
IEEE Publishing Policy

The general IEEE policy requires that authors should only submit original work that has neither appeared elsewhere for publication, nor is under review for another refereed publication. The submitting author must disclose all prior publication(s) and current submissions when submitting a manuscript. Do not publish "preliminary" data or results. The submitting author is responsible for obtaining agreement of all coauthors and any consent required from employers or sponsors before submitting an article. The IEEE Transactions and Journals Department strongly discourages courtesy authorship; it is the obligation of the authors to cite only relevant prior work.

The IEEE Transactions and Journals Department does not publish conference records or proceedings, but can publish articles related to conferences that have undergone rigorous peer review. Minimally, two reviews are required for every article submitted for peer review.

Appendix III
Publication Principles

The two types of contents of that are published are; 1) peer-reviewed and 2) archival. The Transactions and Journals Department publishes scholarly articles of archival value as well as tutorial expositions and critical reviews of classical subjects and topics of current interest.

Authors should consider the following points:

1) Technical papers submitted for publication must advance the state of knowledge and must cite relevant prior work.
2) The length of a submitted paper should be commensurate with the importance, or appropriate to the complexity, of the work. For example, an obvious extension of previously published work might not be appropriate for publication or might be adequately treated in just a few pages.
3) Authors must convince both peer reviewers and the editors of the scientific and technical merit of a paper; the standards of proof are higher when extraordinary or unexpected results are reported.
4) Because replication is required for scientific progress, papers submitted for publication must provide sufficient information to allow readers to perform similar experiments or calculations and use the reported results. Although not everything need be disclosed, a paper must contain new, useable, and fully described information. For example, a specimen's chemical composition need not be reported if the main purpose of a paper is to introduce a new measurement technique. Authors should expect to be challenged by reviewers if the results are not supported by adequate data and critical details.
5) Papers that describe ongoing work or announce the latest technical achievement, which are suitable for presentation at a professional conference, may not be appropriate for publication.

Appendix IV
Reference Examples

- *Basic format for books:*
  J. K. Author, "Title of chapter in the book," in *Title of His Published Book, x*th ed. City of Publisher, (only U.S. State), Country: Abbrev. of Publisher, year, ch. x, sec. x, pp. *xxx–xxx.*
  See [1], [2].
- *Basic format for periodicals:*
  J. K. Author, "Name of paper," *Abbrev. Title of Periodical*, vol. *x, no.* x,pp. *xxx–xxx,* Abbrev. Month, year, DOI. 10.1109.*XXX*.123456.
  See [3]– [5].
- *Basic format for reports:*
  J. K. Author, "Title of report," Abbrev. Name of Co., City of Co., Abbrev. State, Country, Rep. *xxx*, year.
  See [6], [7].
- *Basic format for handbooks:*
  Name of Manual/Handbook, x ed., Abbrev. Name of Co., City of Co., Abbrev. State, Country, year, pp. *xxx–xxx.*
  See [8], [9].
- *Basic format for books (when available online):*
  J. K. Author, "Title of chapter in the book," in *Title of Published Book*, xth ed. City of Publisher, State, Country: Abbrev. of Publisher, year, ch. x, sec. x, pp. *xxx–xxx*.

[Online]. Available: http://www.web.com
See [10]– [13].

- *Basic format for journals (when available online):*
J. K. Author, "Name of paper," *Abbrev. Title of Periodical*, vol. x, no. x, pp. *xxx–xxx*, Abbrev. Month, year. Accessed on: Month, Day, year, DOI: 10.1109.*XXX*.123456, [Online].
See [14]– [16].
- *Basic format for papers presented at conferences (when available online):*
J.K. Author. (year, month). Title. presented at abbrev. conference title. [Type of Medium]. Available: site/path/file
See [17].
- *Basic format for reports and handbooks (when available online):*
J. K. Author. "Title of report," Company. City, State, Country. Rep. no., (optional: vol./issue), Date. [Online] Available: site/path/file
See [18], [19].
- *Basic format for computer programs and electronic documents (when available online):*
Legislative body. Number of Congress, Session. (year, month day). *Number of bill or resolution*, *Title*. [Type of medium]. Available: site/path/file
NOTE: **ISO recommends that capitalization follow the accepted practice for the language or script in which the information is given.**
See [20].
- *Basic format for patents (when available online):*
Name of the invention, by inventor's name. (year, month day). Patent Number [Type of medium]. Available: site/path/file
See [21].
- *Basic formatfor conference proceedings (published):*
J. K. Author, "Title of paper," in *Abbreviated Name of Conf.*, City of Conf., Abbrev. State (if given), Country, year, pp. *xxxxxx.*
See [22].
- *Example for papers presented at conferences (unpublished):*
See [23].
- *Basic format for patents*:
J. K. Author, "Title of patent," U.S. Patent *x xxx xxx*, Abbrev. Month, day, year.
See [24].
- *Basic format for 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.

  See [25], [26].
- *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.

  See [27]– [29].
- *Basic formats for standards:*
  1) *Title of Standard*, Standard number, date.
  2) *Title of Standard*, Standard number, Corporate author, location, date.

  See [30], [31].
- *Article number in reference examples:*
See [32], [33].
- *Example when using et al.:*
See [34].

References

[1] G. O. Young, "Synthetic structure of industrial plastics," in *Plastics,* 2nd ed., vol. 3, J. Peters, Ed. New York, NY, USA: McGraw-Hill, 1964, pp. 15–64.
[2] W.-K. Chen, *Linear Networks and Systems.* Belmont, CA, USA: Wadsworth, 1993, pp. 123–135.
[3] 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, 10.1109/TED.2016.2628402.
[4] E. P. Wigner, "Theory of traveling-wave optical laser," *Phys. Rev*., vol. 134, pp. A635–A646, Dec. 1965.
[5] E. H. Miller, "A note on reflector arrays," *IEEE Trans. Antennas Propagat*., to be published.
[6] E. E. Reber, R. L. Michell, and C. J. Carter, "Oxygen absorption in the earth's atmosphere," Aerospace Corp., Los Angeles, CA, USA, Tech. Rep. TR-0200 (4230-46)-3, Nov. 1988.
[7] J. H. Davis and J. R. Cogdell, "Calibration program for the 16-foot antenna," Elect. Eng. Res. Lab., Univ. Texas, Austin, TX, USA, Tech. Memo. NGL-006-69-3, Nov. 15, 1987.
[8] *Transmission Systems for Communications*, 3rd ed., Western Electric Co., Winston-Salem, NC, USA, 1985, pp. 44–60.
[9] *Motorola Semiconductor Data Manual*, Motorola Semiconductor Products Inc., Phoenix, AZ, USA, 1989.
[10] G. O. Young, "Synthetic structure of industrial plastics," in Plastics, vol. 3, Polymers of Hexadromicon, J. Peters, Ed., 2nd ed. New York, NY, USA: McGraw-Hill, 1964, pp. 15-64. [Online]. Available: http://www.bookref.com.
[11] *The Founders' Constitution*, Philip B. Kurland and Ralph Lerner, eds., Chicago, IL, USA: Univ. Chicago Press, 1987. [Online]. Available: http://press-pubs.uchicago.edu/founders/
[12] The Terahertz Wave eBook. ZOmega Terahertz Corp., 2014. [Online]. Available: http://dl.z-thz.com/eBook/zomega_ebook_pdf_1206_sr.pdf. Accessed on: May 19, 2014.
[13] Philip B. Kurland and Ralph Lerner, eds., *The Founders' Constitution.* Chicago, IL, USA: Univ. of Chicago Press, 1987, Accessed on: Feb. 28, 2010, [Online] Available: http://press-pubs.uchicago.edu/founders/
[14] J. S. Turner, "New directions in communications," *IEEE J. Sel. Areas Commun*., vol. 13, no. 1, pp. 11-23, Jan. 1995.
[15] W. P. Risk, G. S. Kino, and H. J. Shaw, "Fiber-optic frequency shifter using a surface acoustic wave incident at an oblique angle," *Opt. Lett.*, vol. 11, no. 2, pp. 115–117, Feb. 1986.
[16] P. Kopyt *et al., "*Electric properties of graphene-based conductive layers from DC up to terahertz range," *IEEE THz Sci. Technol.,* to be published. DOI: 10.1109/TTHZ.2016.2544142.
[17] PROCESS Corporation, Boston, MA, USA. Intranets: Internet technologies deployed behind the firewall for corporate productivity. Presented at INET96 Annual Meeting. [Online]. Available: http://home.process.com/Intranets/wp2.htp
[18] R. J. Hijmans and J. van Etten, "Raster: Geographic analysis and modeling with raster data," R Package Version 2.0-12, Jan. 12, 2012. [Online]. Available: http://CRAN.R-project.org/package=raster
[19] Teralyzer. Lytera UG, Kirchhain, Germany [Online]. Available: http://www.lytera.de/Terahertz_THz_Spectroscopy.php?id=home, Accessed on: Jun. 5, 2014
[20] U.S. House. 102nd Congress, 1st Session. (1991, Jan. 11). *H. Con. Res. 1, Sense of the Congress on Approval of Military Action*. [Online]. Available: LEXIS Library: GENFED File: BILLS

[21] Musical toothbrush with mirror, by L.M.R. Brooks. (1992, May 19). Patent D 326 189 [Online]. Available: NEXIS Library: LEXPAT File: DES

[22] D. B. Payne and J. R. Stern, "Wavelength-switched pas- sively coupled single-mode optical network," in *Proc. IOOC-ECOC,* Boston, MA, USA, 1985, pp. 585–590.

[23] D. Ebehard and E. Voges, "Digital single sideband detection for interferometric sensors," presented at the 2^{nd} *Int. Conf. Optical Fiber Sensors,* Stuttgart, Germany, Jan. 2-5, 1984.

[24] G. Brandli and M. Dick, "Alternating current fed power supply," U.S. Patent 4 084 217, Nov. 4, 1978.

[25] J. O. Williams, "Narrow-band analyzer," Ph.D. dissertation, Dept. Elect. Eng., Harvard Univ., Cambridge, MA, USA, 1993.

[26] N. Kawasaki, "Parametric study of thermal and chemical nonequilibrium nozzle flow," M.S. thesis, Dept. Electron. Eng., Osaka Univ., Osaka, Japan, 1993.

[27] A. Harrison, private communication, May 1995.

[28] B. Smith, "An approach to graphs of linear forms," unpublished.

[29] A. Brahms, "Representation error for real numbers in binary computer arithmetic," IEEE Computer Group Repository, Paper R-67-85.

[30] IEEE Criteria for Class IE Electric Systems, IEEE Standard 308, 1969.

[31] Letter Symbols for Quantities, ANSI Standard Y10.5-1968.

[32] R. Fardel, M. Nagel, F. Nuesch, T. Lippert, and A. Wokaun, "Fabrication of organic light emitting diode pixels by laser-assisted forward transfer," *Appl. Phys. Lett.*, vol. 91, no. 6, Aug. 2007, Art. no. 061103.

[33] J. Zhang and N. Tansu, "Optical gain and laser characteristics of InGaN quantum wells on ternary InGaN substrates," *IEEE Photon. J.*, vol. 5, no. 2, Apr. 2013, Art. no. 2600111

[34] S. Azodolmolky *et al.*, Experimental demonstration of an impairment aware network planning and operation tool for transparent/translucent optical networks," *J. Lightw. Technol.*, vol. 29, no. 4, pp. 439–448, Sep. 2011.

First A. Author (M'76–SM'81–F'87) and all authors may include biographies. Biographies are often not included in conference-related papers. This author became a Member (M) of IEEE in 1976, a Senior Member (SM) in 1981, and a Fellow (F) in 1987. The first paragraph may contain a place and/or date of birth (list place, then date). Next, the author's educational background is listed. The degrees should be listed with type of degree in what field, which institution, city, state, and country, and year the degree was earned. The author's major field of study should be lower-cased.

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 (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, it should be of good quality, and professional-looking. Following are two examples of an author's biography.

Second B. Author was born in Greenwich Village, New York, NY, USA in 1977. He received the B.S. and M.S. degrees in aerospace engineering from the University of Virginia, Charlottesville, in 2001 and the Ph.D. degree in mechanical engineering from Drexel University, Philadelphia, PA, in 2008.

From 2001 to 2004, he was a Research Assistant with the Princeton Plasma Physics Laboratory. Since 2009, he has been an Assistant Professor with the Mechanical Engineering Department, Texas A&M University, College Station. He is the author of three books, more than 150 articles, and more than 70 inventions. His research interests include high-pressure and high-density nonthermal plasma discharge processes and applications, microscale plasma discharges, discharges in liquids, spectroscopic diagnostics, plasma propulsion, and innovation plasma applications. He is an Associate Editor of the journal *Earth, Moon, Planets*, and holds two patents.

Dr. Author was a recipient of the International Association of Geomagnetism and Aeronomy Young Scientist Award for Excellence in 2008, and the IEEE Electromagnetic Compatibility Society Best Symposium Paper Award in 2011.

Third C. Author, Jr. (M'87) received the B.S. degree in mechanical engineering from National Chung Cheng University, Chiayi, Taiwan, in 2004 and the M.S. degree in mechanical engineering from National Tsing Hua University, Hsinchu, Taiwan, in 2006. He is currently pursuing the Ph.D. degree in mechanical engineering at Texas A&M University, College Station, TX, USA.

From 2008 to 2009, he was a Research Assistant with the Institute of Physics, Academia Sinica, Tapei, Taiwan. His research interest includes the development of surface processing and biological/medical treatment techniques using nonthermal atmospheric pressure plasmas, fundamental study of plasma sources, and fabrication of micro- or nanostructured surfaces.

Mr. Author's awards and honors include the Frew Fellowship (Australian Academy of Science), the I. I. Rabi Prize (APS), the European Frequency and Time Forum Award, the Carl Zeiss Research Award, the William F. Meggers Award and the Adolph Lomb Medal (OSA).