Point-process based representation learning for Electronic Health Records

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***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

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 $m_k \in \{1, ..., M\}$.

A. Event Encoder

We use a similar transformer architecture [thp] for encoding events. The advantage of the attention mechanism is that it discards recurrent architecture. it is necessary to include temporal information. Similar to the original positional encoding [vaswani], we use a temporal encoding procedure:

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

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.

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

B. 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

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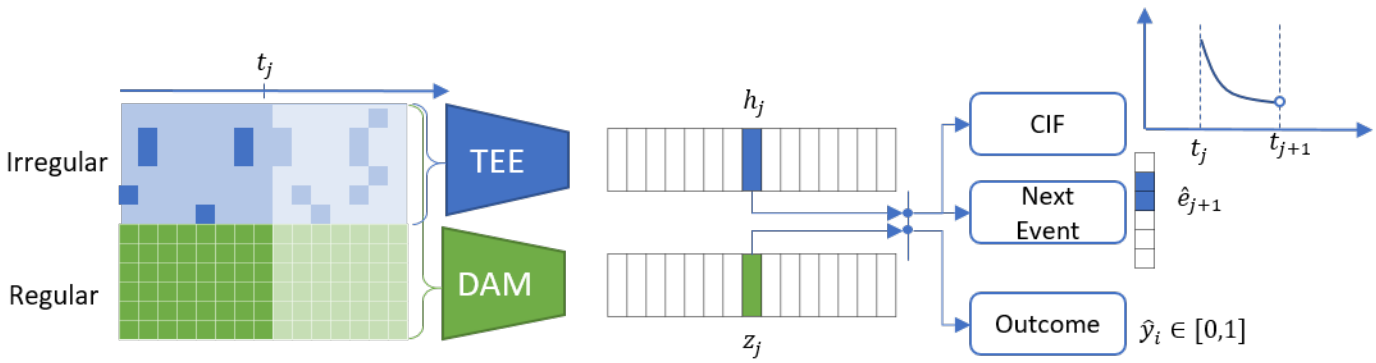

Fig. 1. Magnetization as a function of applied field. It is good practice to explain the significance of the figure in the caption.

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:

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

C. 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:

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

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

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

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

D. 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

B. Negative Likelihood with state encoding

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

can u provide one example patient?

TABLE I
EFFECT

		shp+mark		baseline
Dataset	Metric	concat	sum	
SO	NLL			
	AUROC			
	time			
Synthea	NLL			
	AUROC			
	time			
ReTweet	NLL			
	AUROC			
	time			

TABLE II
NLL ESTIMATION

		Model		
Dataset	setting	TE	TE+DAM	TE+noise
P12	sc			
	mc1			
	mc2			
p19	sc			
	mc1			
	mc2			

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.

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

TABLE III
DOWN STREAM TASK

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

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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 $Ni_{0.5}Mn_{0.5}$ whereas "Ni–Mn" indicates an alloy of some composition Ni_xMn_{1-x}.

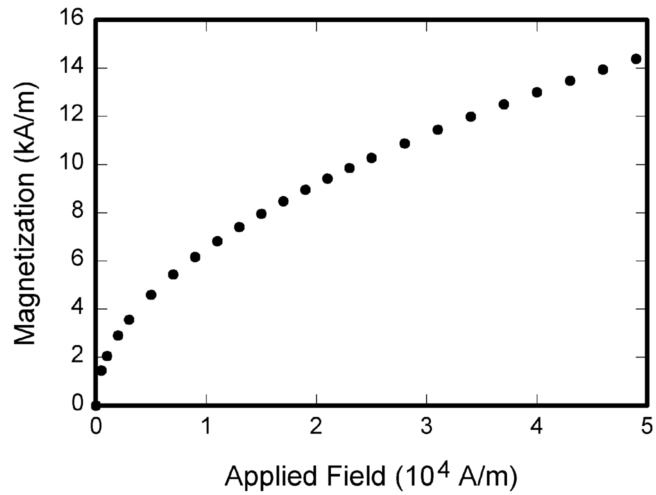

Fig. 2. Magnetization as a function of applied field. It is good practice to explain the significance of the figure in the caption.

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.

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 halftones of gray, only black and white.

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.

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.

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·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.

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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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  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
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  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**

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See [20].

- *Basic format for patents (when available online):*
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  J. K. Author, "Title of paper," in *Abbreviated Name of Conf.*, City of Conf., Abbrev. State (if given), Country, year, pp. *xxxxxx.*
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  See [23].
- *Basic format for patents*:
  J. K. Author, "Title of patent," U.S. Patent *x xxx xxx*, Abbrev. Month, day, year.
  See [24].
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  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].

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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.

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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.

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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).