
A Tractable Model for Generating High-Dimensional Sequences

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Abstract

We propose a tractable probabilistic model for generating complex high dimensional sequences. This model combines a powerful real-valued distribution estimator with a Recurrent Neural Network (RNN) for capturing temporal dependencies in complex, high-dimensional data. Unlike other models in this family, computing probabilities for sequences and sampling from these models is tractable and simple. Therefore the model can be used in combination with other sequential models and not just for generating sequences. We demonstrate the advantages of the model by comparing it on two standard tasks. The

1 Introduction

Recently various neural based models have been proposed for learning modelling high dimensional sequential data. These models have been shown to work much better than standard models such as HMMs and Linear Dynamical Systems. These models include the TRBM, the RTRBM and the RNN-RBM. Although these models work very well for complex high dimensional data, they have several limitations. They cannot be trained exactly because their gradients can't be computed. Also obtaining probabilities from the model is not tractable and often very expensive. These models also suffer from the fact, that the distribution estimators they use are meant for binary data. Even though these models can be extended to model real-value with some approximations, these models are known to have several short-comings. The RNN-NADE is a tractable alternative, however it is unsatisfactory, because the NADE can only model distributions over high-dimensional binary vectors. In this paper we propose a tractable distribution estimator for high-dimensional real-valued sequences by making use of the RNADE which was proposed recently. The proposed model can be trained and sampled from efficiently by back-propagating error gradients through the computational graph. A key advantage of this model over other neural-based sequence models is that getting the likelihoods of the occurrence of sequences is tractable and fast. Because of this, the model can be easily combined with other sequence models and is applicable to various tasks like sequence completion, sequence denoising and classification of complex real-valued sequences. We compare our model's performance to the earlier models and demonstrate its many benefits.

NIPS requires electronic submissions. The electronic submission site is

<http://papers.nips.cc>

Please read carefully the instructions below, and follow them faithfully.

1.1 Style

Papers to be submitted to NIPS 2014 must be prepared according to the instructions presented here. Papers may be only up to eight pages long, including figures. Since 2009 an additional ninth page

containing only cited references is allowed. Papers that exceed nine pages will not be reviewed, or in any other way considered for presentation at the conference.

Please note that this year we have introduced automatic line number generation into the style file (for L^AT_EX 2_ε and Word versions). This is to help reviewers refer to specific lines of the paper when they make their comments. Please do NOT refer to these line numbers in your paper as they will be removed from the style file for the final version of accepted papers.

The margins in 2014 are the same as since 2007, which allow for $\approx 15\%$ more words in the paper compared to earlier years. We are also again using double-blind reviewing. Both of these require the use of new style files.

Authors are required to use the NIPS L^AT_EX style files obtainable at the NIPS website as indicated below. Please make sure you use the current files and not previous versions. Tweaking the style files may be grounds for rejection.

1.2 Retrieval of style files

The style files for NIPS and other conference information are available on the World Wide Web at

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The file `nips2014.pdf` contains these instructions and illustrates the various formatting requirements your NIPS paper must satisfy. L^AT_EX users can choose between two style files: `nips11submit_09.sty` (to be used with L^AT_EX version 2.09) and `nips11submit_e.sty` (to be used with L^AT_EX 2_ε). The file `nips2014.tex` may be used as a “shell” for writing your paper. All you have to do is replace the author, title, abstract, and text of the paper with your own. The file `nips2014.rtf` is provided as a shell for MS Word users.

The formatting instructions contained in these style files are summarized in sections 2, 3, and 4 below.

2 General formatting instructions

The text must be confined within a rectangle 5.5 inches (33 picas) wide and 9 inches (54 picas) long. The left margin is 1.5 inch (9 picas). Use 10 point type with a vertical spacing of 11 points. Times New Roman is the preferred typeface throughout. Paragraphs are separated by 1/2 line space, with no indentation.

Paper title is 17 point, initial caps/lower case, bold, centered between 2 horizontal rules. Top rule is 4 points thick and bottom rule is 1 point thick. Allow 1/4 inch space above and below title to rules. All pages should start at 1 inch (6 picas) from the top of the page.

For the final version, authors’ names are set in boldface, and each name is centered above the corresponding address. The lead author’s name is to be listed first (left-most), and the co-authors’ names (if different address) are set to follow. If there is only one co-author, list both author and co-author side by side.

Please pay special attention to the instructions in section 4 regarding figures, tables, acknowledgments, and references.

3 Headings: first level

First level headings are lower case (except for first word and proper nouns), flush left, bold and in point size 12. One line space before the first level heading and 1/2 line space after the first level heading.

3.1 Headings: second level

Second level headings are lower case (except for first word and proper nouns), flush left, bold and in point size 10. One line space before the second level heading and 1/2 line space after the second level heading.

3.1.1 Headings: third level

Third level headings are lower case (except for first word and proper nouns), flush left, bold and in point size 10. One line space before the third level heading and 1/2 line space after the third level heading.

4 Citations, figures, tables, references

These instructions apply to everyone, regardless of the formatter being used.

4.1 Citations within the text

Citations within the text should be numbered consecutively. The corresponding number is to appear enclosed in square brackets, such as [1] or [2]-[5]. The corresponding references are to be listed in the same order at the end of the paper, in the **References** section. (Note: the standard `BIBTEX` style `unsrt` produces this.) As to the format of the references themselves, any style is acceptable as long as it is used consistently.

As submission is double blind, refer to your own published work in the third person. That is, use “In the previous work of Jones et al. [4]”, not “In our previous work [4]”. If you cite your other papers that are not widely available (e.g. a journal paper under review), use anonymous author names in the citation, e.g. an author of the form “A. Anonymous”.

4.2 Footnotes

Indicate footnotes with a number¹ in the text. Place the footnotes at the bottom of the page on which they appear. Precede the footnote with a horizontal rule of 2 inches (12 picas).²

4.3 Figures

All artwork must be neat, clean, and legible. Lines should be dark enough for purposes of reproduction; art work should not be hand-drawn. The figure number and caption always appear after the figure. Place one line space before the figure caption, and one line space after the figure. The figure caption is lower case (except for first word and proper nouns); figures are numbered consecutively.

Make sure the figure caption does not get separated from the figure. Leave sufficient space to avoid splitting the figure and figure caption.

You may use color figures. However, it is best for the figure captions and the paper body to make sense if the paper is printed either in black/white or in color.

4.4 Tables

All tables must be centered, neat, clean and legible. Do not use hand-drawn tables. The table number and title always appear before the table. See Table 1.

Place one line space before the table title, one line space after the table title, and one line space after the table. The table title must be lower case (except for first word and proper nouns); tables are numbered consecutively.

¹Sample of the first footnote

²Sample of the second footnote

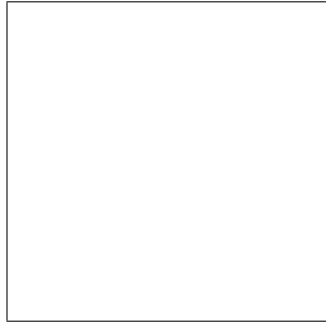


Figure 1: Sample figure caption.

Table 1: Sample table title

PART	DESCRIPTION
Dendrite	Input terminal
Axon	Output terminal
Soma	Cell body (contains cell nucleus)

5 Final instructions

Do not change any aspects of the formatting parameters in the style files. In particular, do not modify the width or length of the rectangle the text should fit into, and do not change font sizes (except perhaps in the **References** section; see below). Please note that pages should be numbered.

6 Preparing PostScript or PDF files

Please prepare PostScript or PDF files with paper size “US Letter”, and not, for example, “A4”. The `-t letter` option on `dvips` will produce US Letter files.

Fonts were the main cause of problems in the past years. Your PDF file must only contain Type 1 or Embedded TrueType fonts. Here are a few instructions to achieve this.

- You can check which fonts a PDF files uses. In Acrobat Reader, select the menu `Files>Document Properties>Fonts` and select `Show All Fonts`. You can also use the program `pdf fonts` which comes with `xpdf` and is available out-of-the-box on most Linux machines.
- The IEEE has recommendations for generating PDF files whose fonts are also acceptable for NIPS. Please see <http://www.emfield.org/icuwb2010/downloads/IEEE-PDF-SpecV32.pdf>
- LaTeX users:
 - Consider directly generating PDF files using `pdflatex` (especially if you are a MiKTeX user). PDF figures must be substituted for EPS figures, however.
 - Otherwise, please generate your PostScript and PDF files with the following commands:


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dvips mypaper.dvi -t letter -Ppdf -G0 -o mypaper.ps
ps2pdf mypaper.ps mypaper.pdf
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 Check that the PDF files only contains Type 1 fonts.
 - `xfig` “patterned” shapes are implemented with bitmap fonts. Use “solid” shapes instead.
 - The `\bbold` package almost always uses bitmap fonts. You can try the equivalent AMS Fonts with command

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216 \usepackage[psamsfonts]{amssymb}
217
218 or use the following workaround for reals, natural and complex:
219 \newcommand{\RR}{\mathbb{R}} %real numbers
220 \newcommand{\Nat}{\mathbb{N}} %natural numbers
221 \newcommand{\CC}{\mathbb{C}} %complex numbers
222
223 – Sometimes the problematic fonts are used in figures included in LaTeX files. The
224 ghostscript program eps2eps is the simplest way to clean such figures. For black
225 and white figures, slightly better results can be achieved with program potrace.
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227 • MSWord and Windows users (via PDF file):
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229 – Install the Microsoft Save as PDF Office 2007 Add-in from http://www.microsoft.com/downloads/details.aspx?displaylang=en&familyid=4d951911-3e7e-4ae6-b059-a2e79ed87041
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231 – Select “Save or Publish to PDF” from the Office or File menu
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233 • MSWord and Mac OS X users (via PDF file):
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235 – From the print menu, click the PDF drop-down box, and select “Save as PDF...”
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237 • MSWord and Windows users (via PS file):
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239 – To create a new printer on your computer, install the AdobePS printer driver
240 and the Adobe Distiller PPD file from http://www.adobe.com/support/downloads/detail.jsp?ftpID=204 Note: You must reboot your PC after
241 installing the AdobePS driver for it to take effect.
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243 – To produce the ps file, select “Print” from the MS app, choose the installed AdobePS
244 printer, click on “Properties”, click on “Advanced.”
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246 – Set “TrueType Font” to be “Download as Softfont”
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248 – Open the “PostScript Options” folder
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250 – Select “PostScript Output Option” to be “Optimize for Portability”
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252 – Select “TrueType Font Download Option” to be “Outline”
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254 – Select “Send PostScript Error Handler” to be “No”
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256 – Click “OK” three times, print your file.
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258 – Now, use Adobe Acrobat Distiller or ps2pdf to create a PDF file from the PS file. In
259 Acrobat, check the option “Embed all fonts” if applicable.

```

If your file contains Type 3 fonts or non embedded TrueType fonts, we will ask you to fix it.

6.1 Margins in LaTeX

Most of the margin problems come from figures positioned by hand using `\special` or other commands. We suggest using the command `\includegraphics` from the `graphicx` package. Always specify the figure width as a multiple of the line width as in the example below using `.eps` graphics

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259 \usepackage[dvips]{graphicx} ...
260 \includegraphics[width=0.8\linewidth]{myfile.eps}
261
262 or
263
264 \usepackage[pdftex]{graphicx} ...
265 \includegraphics[width=0.8\linewidth]{myfile.pdf}

```

for `.pdf` graphics. See section 4.4 in the graphics bundle documentation (<http://www.ctan.org/tex-archive/macros/latex/required/graphics/grfguide.ps>)

A number of width problems arise when LaTeX cannot properly hyphenate a line. Please give LaTeX hyphenation hints using the `\-` command.

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Acknowledgments

Use unnumbered third level headings for the acknowledgments. All acknowledgments go at the end of the paper. Do not include acknowledgments in the anonymized submission, only in the final paper.

References

References follow the acknowledgments. Use unnumbered third level heading for the references. Any choice of citation style is acceptable as long as you are consistent. It is permissible to reduce the font size to ‘small’ (9-point) when listing the references. **Remember that this year you can use a ninth page as long as it contains *only* cited references.**

- [1] Alexander, J.A. & Mozer, M.C. (1995) Template-based algorithms for connectionist rule extraction. In G. Tesauero, D. S. Touretzky and T.K. Leen (eds.), *Advances in Neural Information Processing Systems 7*, pp. 609-616. Cambridge, MA: MIT Press.
- [2] Bower, J.M. & Beeman, D. (1995) *The Book of GENESIS: Exploring Realistic Neural Models with the GEneral NEural Simulation System*. New York: TELOS/Springer-Verlag.
- [3] Hasselmo, M.E., Schnell, E. & Barkai, E. (1995) Dynamics of learning and recall at excitatory recurrent synapses and cholinergic modulation in rat hippocampal region CA3. *Journal of Neuroscience* **15**(7):5249-5262.