

Learning PSRs with The Base System

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1. PROBLEM AND MOTIVATION

We consider the problem of learning models of time series data in partially observable environments. Typical applications arise in robotics and reinforcement learning, where hidden markov models (HMMs) are often the model of choice. We take particular interest in the class of partially observable systems which are compressible, namely systems in which one can achieve good performance with a smaller model. There exists a well known spectral algorithm for learning a Predictive State Representation of the environment from empirical data [NAME]. Traditionally, truncation of this learned PSR has been performed naively. We provide an extension to [NAME]’s algorithm for improved learning of smaller models. In empirical tests, our approach strongly outperforms it’s ancestor in both in predictive and computational performance.

2. BACKGROUND AND RELATED WORK

Predictive state representations are used as a model for predicting the probability of observations in a dynamical system. [NAME] gives an algorithm which makes use of Hankel matrices and a singular value decomposition to obtain a PSR from data. One can control the number of states in the PSR by including states with highest singular values. The reason for using less states is twofold. First, noise in empirical data artificial creates states with low singular values. Secondly, reducing the number of states is necessary in practice for computational performance.

Previous work with PSR learning has included planning [pierre luc] and natural language processing [other source]. Our work focuses on improving the learning of PSRs for general applications.

3. APPROACH AND UNIQUENESS

In our work, we extend the standard PSR learning algorithm by developing a new machinery for performing queries which we call The Base System. This extra machinery allows us to

richly express state transitions with truncated models and provides better experimental performance. We first apply this system to timing applications where the construction of the Base System is easiest to standardize. We then progress to the general case of systems with multiple observations and develop a heuristic for constructing the Base System effectively from data.

4. RESULTS AND CONTRIBUTIONS

4.1 Experiments

In the experiments that follow, we produce observations by simulating robot motion in labyrinth environments. We compare PSRs which use the base system to different degrees. To measure performance, the predictions of each PSR are compared to the actual probability distribution of the observations.

In the first experiment we look at the time spent in double loop systems. In both cases, the PSR with the Base System has 100 % less error than without. In particular, we note that noise in the durations of loops doesn’t harm the performance of the Base.

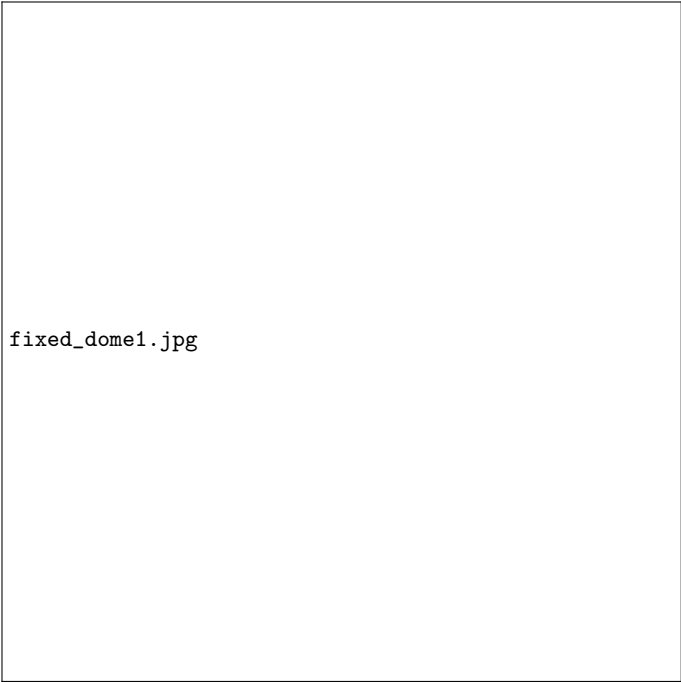
In the second experiment, we look at timing for a PacMan-Type labyrinth. In addition, we use state weightings from the learned PSRs to predict distances between the robot and objects in the environment.

We now extend our set of observations to multiple wall colors rather than the single observation case of time. Our base system expands by including powers of all symbols. Note that in some environments, powers of a mixture of symbols may be the way to go. We leave the decision of choosing powers up to the user, as it is dependent on the choice of application.

4.2 Relevance

The spectral framework for learning in partially observable environments has better theoretical guarantees [REFERENCE] than non-spectral methods. In this work, we showed a way to significantly improve results in practical settings, that is when one wants a smaller model. In future work, we hope to see a theoretical analysis of the apparent improvement and optimization in how one constructs the Base System for the multiple observation case.

The *proceedings* are the records of a conference. ACM seeks to give these conference by-products a uniform, high-quality



fixed_dome1.jpg

Figure 1: A simple caption

appearance. To do this, ACM has some rigid requirements for the format of the proceedings documents: there is a specified format (balanced double columns), a specified set of fonts (Arial or Helvetica and Times Roman) in certain specified sizes (for instance, 9 point for body copy), a specified live area (18×23.5 cm [7×9.25 "]) centered on the page, specified size of margins (1.9 cm [0.75"]) top, (2.54 cm [1"]) bottom and (1.9 cm [.75"]) left and right; specified column width (8.45 cm [3.33"]) and gutter size (.83 cm [.33]).

The good news is, with only a handful of manual settings¹, the L^AT_EX document class file handles all of this for you.

The remainder of this document is concerned with showing, in the context of an "actual" document, the L^AT_EX commands specifically available for denoting the structure of a proceedings paper, rather than with giving rigorous descriptions or explanations of such commands.

5. PROBLEM AND MOTIVATION

Typically, the body of a paper is organized into a hierarchical structure, with numbered or unnumbered headings for sections, subsections, sub-subsections, and even smaller sections. The command `\section` that precedes this paragraph is part of such a hierarchy.² L^AT_EX handles the numbering and placement of these headings for you, when you use the appropriate heading commands around the titles of the

¹Two of these, the `\numberofauthors` and `\alignauthor` commands, you have already used; another, `\balancecolumns`, will be used in your very last run of L^AT_EX to ensure balanced column heights on the last page.

²This is the second footnote. It starts a series of three footnotes that add nothing informational, but just give an idea of how footnotes work and look. It is a wordy one, just so you see how a longish one plays out.

headings. If you want a sub-subsection or smaller part to be unnumbered in your output, simply append an asterisk to the command name. Examples of both numbered and unnumbered headings will appear throughout the balance of this sample document.

Because the entire article is contained in the `document` environment, you can indicate the start of a new paragraph with a blank line in your input file; that is why this sentence forms a separate paragraph.

5.1 Type Changes and *Special Characters*

We have already seen several typeface changes in this sample. You can indicate italicized words or phrases in your text with the command `\textit`; emboldening with the command `\textbf` and typewriter-style (for instance, for computer code) with `\texttt`. But remember, you do not have to indicate typestyle changes when such changes are part of the *structural* elements of your article; for instance, the heading of this subsection will be in a sans serif³ typeface, but that is handled by the document class file. Take care with the use of⁴ the curly braces in typeface changes; they mark the beginning and end of the text that is to be in the different typeface.

You can use whatever symbols, accented characters, or non-English characters you need anywhere in your document; you can find a complete list of what is available in the *L^AT_EX User's Guide*[?].

5.2 Math Equations

You may want to display math equations in three distinct styles: inline, numbered or non-numbered display. Each of the three are discussed in the next sections.

5.2.1 Inline (In-text) Equations

A formula that appears in the running text is called an inline or in-text formula. It is produced by the `math` environment, which can be invoked with the usual `\begin. . . \end` construction or with the short form `$. . . $`. You can use any of the symbols and structures, from α to ω , available in L^AT_EX[?]; this section will simply show a few examples of in-text equations in context. Notice how this equation: $\lim_{n \rightarrow \infty} x = 0$, set here in in-line math style, looks slightly different when set in display style. (See next section).

5.2.2 Display Equations

A numbered display equation – one set off by vertical space from the text and centered horizontally – is produced by the `equation` environment. An unnumbered display equation is produced by the `displaymath` environment.

Again, in either environment, you can use any of the symbols and structures available in L^AT_EX; this section will just give a couple of examples of display equations in context. First, consider the equation, shown as an inline equation above:

$$\lim_{n \rightarrow \infty} x = 0 \tag{1}$$

³A third footnote, here. Let's make this a rather short one to see how it looks.

⁴A fourth, and last, footnote.

Table 1: Frequency of Special Characters

Non-English or Math	Frequency	Comments
Ø	1 in 1,000	For Swedish names
π	1 in 5	Common in math
\$	4 in 5	Used in business
Ψ ₁ ²	1 in 40,000	Unexplained usage

Notice how it is formatted somewhat differently in the **displaymath** environment. Now, we'll enter an unnumbered equation:

$$\sum_{i=0}^{\infty} x + 1$$

and follow it with another numbered equation:

$$\sum_{i=0}^{\infty} x_i = \int_0^{\pi+2} f \quad (2)$$

just to demonstrate L^AT_EX's able handling of numbering.

5.3 Citations

Citations to articles [?, ?, ?, ?], conference proceedings [?] or books [?, ?] listed in the Bibliography section of your article will occur throughout the text of your article. You should use BibTeX to automatically produce this bibliography; you simply need to insert one of several citation commands with a key of the item cited in the proper location in the .tex file [?]. The key is a short reference you invent to uniquely identify each work; in this sample document, the key is the first author's surname and a word from the title. This identifying key is included with each item in the .bib file for your article.

The details of the construction of the .bib file are beyond the scope of this sample document, but more information can be found in the *Author's Guide*, and exhaustive details in the *L^AT_EX User's Guide*[?].

This article shows only the plainest form of the citation command, using `\cite`. This is what is stipulated in the SIGS style specifications. No other citation format is endorsed.

5.4 Tables

Because tables cannot be split across pages, the best placement for them is typically the top of the page nearest their initial cite. To ensure this proper "floating" placement of tables, use the environment **table** to enclose the table's contents and the table caption. The contents of the table itself must go in the **tabular** environment, to be aligned properly in rows and columns, with the desired horizontal and vertical rules. Again, detailed instructions on **tabular** material is found in the *L^AT_EX User's Guide*.

Immediately following this sentence is the point at which Table 1 is included in the input file; compare the placement of the table here with the table in the printed dvi output of this document.

To set a wider table, which takes up the whole width of the page's live area, use the environment **table*** to enclose the table's contents and the table caption. As with

Figure 2: A sample black and white graphic (.eps format).

Figure 3: A sample black and white graphic (.eps format) that has been resized with the epsfig command.

a single-column table, this wide table will "float" to a location deemed more desirable. Immediately following this sentence is the point at which Table 2 is included in the input file; again, it is instructive to compare the placement of the table here with the table in the printed dvi output of this document.

5.5 Figures

Like tables, figures cannot be split across pages; the best placement for them is typically the top or the bottom of the page nearest their initial cite. To ensure this proper "floating" placement of figures, use the environment **figure** to enclose the figure and its caption.

This sample document contains examples of .eps and .ps files to be displayable with L^AT_EX. More details on each of these is found in the *Author's Guide*.

As was the case with tables, you may want a figure that spans two columns. To do this, and still to ensure proper "floating" placement of tables, use the environment **figure*** to enclose the figure and its caption.

Note that either .ps or .eps formats are used; use the `\epsfig` or `\psfig` commands as appropriate for the different file types.

5.6 Theorem-like Constructs

Other common constructs that may occur in your article are the forms for logical constructs like theorems, axioms, corollaries and proofs. There are two forms, one produced by the command `\newtheorem` and the other by the command `\newdef`; perhaps the clearest and easiest way to distinguish them is to compare the two in the output of this sample document:

This uses the **theorem** environment, created by the `\newtheorem` command:

THEOREM 1. *Let f be continuous on $[a, b]$. If G is an antiderivative for f on $[a, b]$, then*

$$\int_a^b f(t)dt = G(b) - G(a).$$

The other uses the **definition** environment, created by the `\newdef` command:

Definition 1. *If z is irrational, then by e^z we mean the unique number which has logarithm z :*

$$\log e^z = z$$

Table 2: Some Typical Commands

Command	A Number	Comments
<code>\alignauthor</code>	100	Author alignment
<code>\numberofauthors</code>	200	Author enumeration
<code>\table</code>	300	For tables
<code>\table*</code>	400	For wider tables

Figure 4: A sample black and white graphic (.ps format) that has been resized with the `psfig` command.

Two lists of constructs that use one of these forms is given in the *Author's Guidelines*.

and don't forget to end the environment with `figure*`, not `figure`!

There is one other similar construct environment, which is already set up for you; i.e. you must *not* use a `\newdef` command to create it: the **proof** environment. Here is an example of its use:

PROOF. Suppose on the contrary there exists a real number L such that

$$\lim_{x \rightarrow \infty} \frac{f(x)}{g(x)} = L.$$

Then

$$l = \lim_{x \rightarrow c} f(x) = \lim_{x \rightarrow c} \left[g(x) \cdot \frac{f(x)}{g(x)} \right] = \lim_{x \rightarrow c} g(x) \cdot \lim_{x \rightarrow c} \frac{f(x)}{g(x)} = 0 \cdot L = 0,$$

which contradicts our assumption that $l \neq 0$. \square

Complete rules about using these environments and using the two different creation commands are in the *Author's Guide*; please consult it for more detailed instructions. If you need to use another construct, not listed therein, which you want to have the same formatting as the Theorem or the Definition[?] shown above, use the `\newtheorem` or the `\newdef` command, respectively, to create it.

A Caveat for the T_EX Expert

Because you have just been given permission to use the `\newdef` command to create a new form, you might think you can use T_EX's `\def` to create a new command: *Please refrain from doing this!* Remember that your L^AT_EX source code is primarily intended to create camera-ready copy, but may be converted to other forms – e.g. HTML. If you inadvertently omit some or all of the `\defs` recompilation will be, to say the least, problematic.

6. CONCLUSIONS

This paragraph will end the body of this sample document. Remember that you might still have Acknowledgments or Appendices; brief samples of these follow. There is still the Bibliography to deal with; and we will make a disclaimer about that here: with the exception of the reference to the L^AT_EX book, the citations in this paper are to articles which have nothing to do with the present subject and are used as examples only.

7. ACKNOWLEDGMENTS

This section is optional; it is a location for you to acknowledge grants, funding, editing assistance and what have you. In the present case, for example, the authors would like to thank Gerald Murray of ACM for his help in codifying this *Author's Guide* and the `.cls` and `.tex` files that it describes.

APPENDIX

A. HEADINGS IN APPENDICES

The rules about hierarchical headings discussed above for the body of the article are different in the appendices. In the **appendix** environment, the command **section** is used to indicate the start of each Appendix, with alphabetic order designation (i.e. the first is A, the second B, etc.) and a title (if you include one). So, if you need hierarchical structure *within* an Appendix, start with **subsection** as the highest level. Here is an outline of the body of this document in Appendix-appropriate form:

A.1 Introduction

A.2 The Body of the Paper

A.2.1 Type Changes and Special Characters

A.2.2 Math Equations

Inline (In-text) Equations

Display Equations

A.2.3 Citations

A.2.4 Tables

A.2.5 Figures

A.2.6 Theorem-like Constructs

A Caveat for the T_EX Expert

A.3 Conclusions

A.4 Acknowledgments

A.5 Additional Authors

This section is inserted by L^AT_EX; you do not insert it. You just add the names and information in the `\additionalauthors` command at the start of the document.

A.6 References

Generated by bibtex from your `.bib` file. Run latex, then bibtex, then latex twice (to resolve references) to create the `.bbl` file. Insert that `.bbl` file into the `.tex` source file and comment out the command `\thebibliography`.

Figure 5: A sample black and white graphic (.eps format) that needs to span two columns of text.

B. MORE HELP FOR THE HARDY

The `acm_proc_article-sp` document class file itself is chock-full of succinct and helpful comments. If you consider yourself a moderately experienced to expert user of \LaTeX , you may find reading it useful but please remember not to change it.