

A Generative Model for Brain Tumor Segmentation in Multi-Modal Images

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Abstract

For this project I chose to attempt to replicate a paper by Bjoern H. Menze, Koen Van Leemput and others[1]. In the paper they describe how to build and train a generative model for brain tumor segmentation of multi-modal images. The method is fully automatic, requiring only the images and a probabilistic tissue map, which is assumed to be known.

1. Introduction

MRI (magnetic resonance imaging) is a common imaging method for the study of brain tumors. As such there is a need to be able to automatically identify tumors in the scans of a subject. Furthermore modern MRI machines can produce several different types of scans, for example FLAIR, which suppress' cerebrospinal fluid effects on an image, and often images for a patient are available for several different modalities. Standard multi-modal segmentations (at the time the article was written) find a single tumor region for all modalities, however tumor areas may be delineated differently in each modality. Therefore, delineating tumor areas separately in each modality would be ideal for any further analysis. To that end the authors presented a generative model for multi-modal tumor segmentation that allows for different segmentations in each modality. For comparison the authors also segmented the images using an EM segmentation similar to [2]. The authors showed a significant improvement in Dice scores for all modalities they tested (T1, T1 gad, T2 and Flair).

2. Theory

Discriminative models attempt to directly predict the desired quantity $p(y|x)$ (y is the presence of tumors in this case), and so, do not consider spatial priors. To do so they generally require lots of training data. They are also generally limited to the modalities present in the training data. Generative models model the joint probability distribution

$p(x, y)$ and use bayes theorem to try and compute $p(y|x)$. Using bayes, however, requires knowing the spatial prior for lesions, which can be difficult to compute. To solve this problem the authors model uses an EM like algorithm to derive a spatial prior (for a particular patient) for tumor tissue. The model also includes a spatial prior on healthy tissues. For their paper, and my project, $K = 3$ healthy tissue types were considered, white matter, gray matter and cerebrospinal fluid. See 1 for an illustration of the model.

2.1. Model

The prior on normal tissue state K is modeled with π_k , which is a spatial probability map, or atlas, for the 3 tissue types, and is assumed to be known. The atlas defines, for each voxel i , a probability of belonging to the k^{th} tissue class:

$$p(k_i = k) = \pi_{ki} \quad (1)$$

The model also uses a latent atlas α , which is unknown and derived as part of the algorithm. The latent alpha parametrizes t , which is the probability of a tumor at voxel i . t takes values $\{0, 1\}$ and is modelled as a binomial random variable with probability α

$$p(t_i = 1) = \alpha_i \quad (2)$$

Observations, \mathbf{y} , are generated by gaussian intensity distributions. An intensity distribution parameter θ holds parameters μ_k^c and v_k^c for each of the C channels and K tissue classes, μ_{k+1}^c and v_{k+1}^c are added for each channel to represent the tumor class. For each voxel i the vector $\mathbf{y}_i = [y_i^1, \dots, y_i^c]$ represents the image observations across all C channels. Similarly the vector $\mathbf{t}_i = [t_i^1, \dots, t_i^c]$ represents the tumor state for all channels at voxel i . The authors state the joint probability:

$$p(\mathbf{y}_i, \mathbf{t}_i, k_i; \theta, \alpha_i) = p(\mathbf{y}_i | \mathbf{t}_i, k_i; \theta) \cdot p(\mathbf{t}_i; \alpha_i) \cdot p(k_i) \quad (3)$$

Equation 4 in [1](See also equations 1,2,3 in [1])

2.2. Maximum Likelihood and EM

The intended goal is to find optimal parameters $\{\tilde{\theta}, \tilde{\alpha}\}$, that maximize the likelihood of the observations $\mathbf{y}_1, \dots, \mathbf{y}_N$,

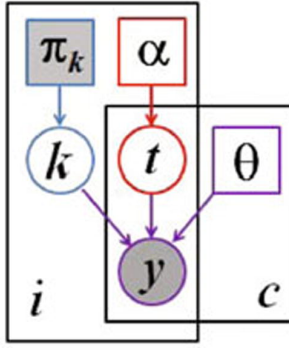


Figure 1. Graphical model from [1]. Only shaded values are known. π_k is the known prior for healthy tissue. y are image observations

where N is the number of voxels

2.3. Tumor segmentation

CVPR papers may be between 6 pages and 8 pages, with a \$100 per page added fee. Overlength papers will simply not be reviewed. This includes papers where the margins and formatting are deemed to have been significantly altered from those laid down by this style guide. Note that this L^AT_EX guide already sets figure captions and references in a smaller font. The reason such papers will not be reviewed is that there is no provision for supervised revisions of manuscripts. The reviewing process cannot determine the suitability of the paper for presentation in eight pages if it is reviewed in eleven. If you submit 8 for review expect to pay the added page charges for them.

2.4. The ruler

The L^AT_EX style defines a printed ruler which should be present in the version submitted for review. The ruler is provided in order that reviewers may comment on particular lines in the paper without circumlocution. If you are preparing a document using a non-L^AT_EX document preparation system, please arrange for an equivalent ruler to appear on the final output pages. The presence or absence of the ruler should not change the appearance of any other content on the page. The camera ready copy should not contain a ruler. (L^AT_EX users may uncomment the `\cvprfinalcopy` command in the document preamble.) Reviewers: note that the ruler measurements do not align well with lines in the paper — this turns out to be very difficult to do well when the paper contains many figures and equations, and, when done, looks ugly. Just use fractional references (e.g. this line is 095.5), although in most cases one would expect that the approximate location will be adequate.

2.5. Mathematics

Please number all of your sections and displayed equations. It is important for readers to be able to refer to any particular equation. Just because you didn't refer to it in the text doesn't mean some future reader might not need to refer to it. It is cumbersome to have to use circumlocutions like "the equation second from the top of page 3 column 1". (Note that the ruler will not be present in the final copy, so is not an alternative to equation numbers). All authors will benefit from reading Mermin's description of how to write mathematics: <http://www.pamitc.org/documents/mermin.pdf>.

2.6. Blind review

Many authors misunderstand the concept of anonymizing for blind review. Blind review does not mean that one must remove citations to one's own work—in fact it is often impossible to review a paper unless the previous citations are known and available.

Blind review means that you do not use the words "my" or "our" when citing previous work. That is all. (But see below for techreports)

Saying "this builds on the work of Lucy Smith [1]" does not say that you are Lucy Smith, it says that you are building on her work. If you are Smith and Jones, do not say "as we show in [7]", say "as Smith and Jones show in [7]" and at the end of the paper, include reference 7 as you would any other cited work.

An example of a bad paper just asking to be rejected:

An analysis of the frobnicatable foo filter.

In this paper we present a performance analysis of our previous paper [1], and show it to be inferior to all previously known methods. Why the previous paper was accepted without this analysis is beyond me.

[1] Removed for blind review

An example of an acceptable paper:

An analysis of the frobnicatable foo filter.

In this paper we present a performance analysis of the paper of Smith *et al.* [1], and show it to be inferior to all previously known methods. Why the previous paper was accepted without this analysis is beyond me.

[1] Smith, L and Jones, C. "The frobnicatable foo filter, a fundamental contribution to human knowledge". Nature 381(12), 1-213.

If you are making a submission to another conference at the same time, which covers similar or overlapping material, you may need to refer to that submission in order to

explain the differences, just as you would if you had previously published related work. In such cases, include the anonymized parallel submission [?] as additional material and cite it as

[1] Authors. “The frobnicatable foo filter”, F&G 2014 Submission ID 324, Supplied as additional material fg324.pdf.

Finally, you may feel you need to tell the reader that more details can be found elsewhere, and refer them to a technical report. For conference submissions, the paper must stand on its own, and not *require* the reviewer to go to a techreport for further details. Thus, you may say in the body of the paper “further details may be found in [?]”. Then submit the techreport as additional material. Again, you may not assume the reviewers will read this material.

Sometimes your paper is about a problem which you tested using a tool which is widely known to be restricted to a single institution. For example, let’s say it’s 1969, you have solved a key problem on the Apollo lander, and you believe that the CVPR70 audience would like to hear about your solution. The work is a development of your celebrated 1968 paper entitled “Zero-g frobnication: How being the only people in the world with access to the Apollo lander source code makes us a wow at parties”, by Zeus *et al.*

You can handle this paper like any other. Don’t write “We show how to improve our previous work [Anonymous, 1968]. This time we tested the algorithm on a lunar lander [name of lander removed for blind review]”. That would be silly, and would immediately identify the authors. Instead write the following:

We describe a system for zero-g frobnication. This system is new because it handles the following cases: A, B. Previous systems [Zeus et al. 1968] didn’t handle case B properly. Ours handles it by including a foo term in the bar integral.

...

The proposed system was integrated with the Apollo lunar lander, and went all the way to the moon, don’t you know. It displayed the following behaviours which show how well we solved cases A and B: ...

As you can see, the above text follows standard scientific convention, reads better than the first version, and does not explicitly name you as the authors. A reviewer might think it likely that the new paper was written by Zeus *et al.*, but cannot make any decision based on that guess. He or she would have to be sure that no other authors could have been contracted to solve problem B.

FAQ: Are acknowledgements OK? No. Leave them for the final copy.

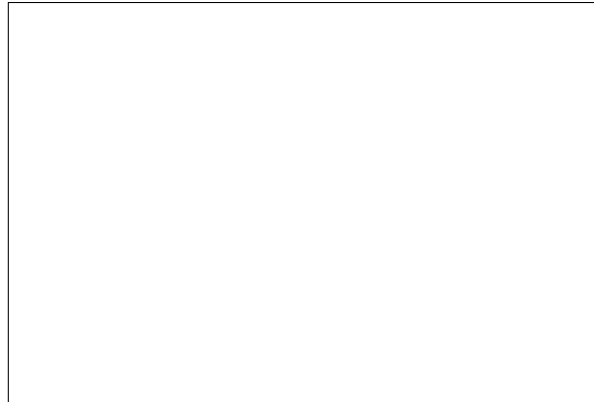


Figure 2. Example of caption. It is set in Roman so that mathematics (always set in Roman: $B \sin A = A \sin B$) may be included without an ugly clash.

2.7. Miscellaneous

Compare the following:

$\$conf_a\$$ $conf_a$
 $\$\mathit{conf}_a\$$ $conf_a$

See The T_EXbook, p165.

The space after *e.g.*, meaning “for example”, should not be a sentence-ending space. So *e.g.* is correct, *e.g.* is not. The provided `\eg` macro takes care of this.

When citing a multi-author paper, you may save space by using “et alia”, shortened to “*et al.*” (not “*et. al.*” as “*et*” is a complete word.) However, use it only when there are three or more authors. Thus, the following is correct: “Frobnication has been trendy lately. It was introduced by Alpher [?], and subsequently developed by Alpher and Fotheringham-Smythe [?], and Alpher *et al.* [?].”

This is incorrect: “... subsequently developed by Alpher *et al.* [?] ...” because reference [?] has just two authors. If you use the `\etal` macro provided, then you need not worry about double periods when used at the end of a sentence as in Alpher *et al.*

For this citation style, keep multiple citations in numerical (not chronological) order, so prefer [?, ?, ?] to [?, ?, ?].

3. Formatting your paper

All text must be in a two-column format. The total allowable width of the text area is $6\frac{7}{8}$ inches (17.5 cm) wide by $8\frac{7}{8}$ inches (22.54 cm) high. Columns are to be $3\frac{1}{4}$ inches (8.25 cm) wide, with a $\frac{5}{16}$ inch (0.8 cm) space between them. The main title (on the first page) should begin 1.0 inch (2.54 cm) from the top edge of the page. The second and following pages should begin 1.0 inch (2.54 cm) from the top edge. On all pages, the bottom margin should be 1-1/8 inches (2.86 cm) from the bottom edge of the page for 8.5 × 11-inch paper; for A4 paper, approximately 1-5/8 inches (4.13 cm) from the bottom edge of the page.



Figure 3. Example of a short caption, which should be centered.

3.1. Margins and page numbering

All printed material, including text, illustrations, and charts, must be kept within a print area 6-7/8 inches (17.5 cm) wide by 8-7/8 inches (22.54 cm) high. Page numbers should be in footer with page numbers, centered and .75 inches from the bottom of the page and make it start at the correct page number rather than the 4321 in the example. To do this fine the line (around line 23)

```
%\ifcvprfinal\pagestyle{empty}\fi  
\setcounter{page}{4321}
```

where the number 4321 is your assigned starting page.

Make sure the first page is numbered by commenting out the first page being empty on line 46

```
%\thispagestyle{empty}
```

3.2. Type-style and fonts

Wherever Times is specified, Times Roman may also be used. If neither is available on your word processor, please use the font closest in appearance to Times to which you have access.

MAIN TITLE. Center the title 1-3/8 inches (3.49 cm) from the top edge of the first page. The title should be in Times 14-point, boldface type. Capitalize the first letter of nouns, pronouns, verbs, adjectives, and adverbs; do not capitalize articles, coordinate conjunctions, or prepositions (unless the title begins with such a word). Leave two blank lines after the title.

AUTHOR NAME(s) and **AFFILIATION(s)** are to be centered beneath the title and printed in Times 12-point, non-boldface type. This information is to be followed by two blank lines.

The **ABSTRACT** and **MAIN TEXT** are to be in a two-column format.

MAIN TEXT. Type main text in 10-point Times, single-spaced. Do NOT use double-spacing. All paragraphs

should be indented 1 pica (approx. 1/6 inch or 0.422 cm). Make sure your text is fully justified—that is, flush left and flush right. Please do not place any additional blank lines between paragraphs.

Figure and table captions should be 9-point Roman type as in Figures 2 and 3. Short captions should be centred.

Callouts should be 9-point Helvetica, non-boldface type. Initially capitalize only the first word of section titles and first-, second-, and third-order headings.

FIRST-ORDER HEADINGS. (For example, **1. Introduction**) should be Times 12-point boldface, initially capitalized, flush left, with one blank line before, and one blank line after.

SECOND-ORDER HEADINGS. (For example, **1.1. Database elements**) should be Times 11-point boldface, initially capitalized, flush left, with one blank line before, and one after. If you require a third-order heading (we discourage it), use 10-point Times, boldface, initially capitalized, flush left, preceded by one blank line, followed by a period and your text on the same line.

3.3. Footnotes

Please use footnotes¹ sparingly. Indeed, try to avoid footnotes altogether and include necessary peripheral observations in the text (within parentheses, if you prefer, as in this sentence). If you wish to use a footnote, place it at the bottom of the column on the page on which it is referenced. Use Times 8-point type, single-spaced.

3.4. References

List and number all bibliographical references in 9-point Times, single-spaced, at the end of your paper. When referenced in the text, enclose the citation number in square brackets, for example [?]. Where appropriate, include the name(s) of editors of referenced books.[1]

¹This is what a footnote looks like. It often distracts the reader from the main flow of the argument.

Method	Frobnability
Theirs	Frumpy
Yours	Frobbly
Ours	Makes one's heart Frob

Table 1. Results. Ours is better.

3.5. Illustrations, graphs, and photographs

All graphics should be centered. Please ensure that any point you wish to make is resolvable in a printed copy of the paper. Resize fonts in figures to match the font in the body text, and choose line widths which render effectively in print. Many readers (and reviewers), even of an electronic copy, will choose to print your paper in order to read it. You cannot insist that they do otherwise, and therefore must not assume that they can zoom in to see tiny details on a graphic.

When placing figures in \LaTeX , it's almost always best to use `\includegraphics`, and to specify the figure width as a multiple of the line width as in the example below

```
\usepackage[dvips]{graphicx} ...
\includegraphics[width=0.8\linewidth]
{myfile.eps}
```

3.6. Color

Color is valuable, and will be visible to readers of the electronic copy. However ensure that, when printed on a monochrome printer, no important information is lost by the conversion to grayscale.

4. Final copy

You must include your signed IEEE copyright release form when you submit your finished paper. We **MUST** have this form before your paper can be published in the proceedings.

References

- [1] B. H. Menze, K. Leemput, D. Lashkari, M.-A. Weber, N. Ayache, and P. Golland. *Medical Image Computing and Computer-Assisted Intervention – MICCAI 2010: 13th International Conference, Beijing, China, September 20-24, 2010, Proceedings, Part II*, chapter A Generative Model for Brain Tumor Segmentation in Multi-Modal Images, pages 151–159. Springer Berlin Heidelberg, Berlin, Heidelberg, 2010.
- [2] M. Prastawa, E. Bullitt, S. Ho, and G. Gerig. A brain tumor segmentation framework based on outlier detection. *Medical Image Analysis*, 8(3):275–283, 9 2004.