## Cervical Spine Fracture Detection and Localization

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#### Abstract

Purpose: To develop a deep learning model for the detection and localization of cervical spine fractures in the axial CT scans. Methods: We use the dataset consisting of cervical spine CT scans provided by the Radiological Society of North America (RSNA). The dataset consists of 3000 studies of individual patients for the training and testing combined. Out of these 3000 patient studies, 83 of these studies also contains segmentation data. Additionally, for x studies the dataset contains bounding box coordinates data. The dataset population is split into 90% for training and 10% for validation. We use EfficientNet[1] to learn the segmentation, X model for detecting the fractures and Y model for drawing bounding boxes around the fracture area. Results: Results Conclusion: ability of model localize axial CTcervical spine fractures on radiographs with high sensitivity and specificity demonstrated.

Keywords: Cervical Spine, Fracture Detection, Deep Learning

#### 1 Introduction

Cervical spine injury is very common injury with more than 3 million cases per year that are being evaluated for cervical spine injury in North America[2]. In United States, more than 1 million patients with blunt force injury are suspected to suffer cervical spine injury[3]. Since cervical spine injury is associated

with high morbidity and mortality, quick diagnosis of the injury is crucial. Any delay in diagnosis may result in devastating consequences for the patient. So, any additional aid to the radiologists can reduce the morbidity or mortality of the patient.

In recent years, a machine deep learning technique known as deep convolutional neural network (DCNN) has been applied to image recognition tasks. DCNN's are well suited for images. So, they have been used extensively in the field of medicine to classify medical images.

In past few years, there have been many studies that have tried to use DCNN[4][5][6] on medical radiographs. In these studies, the reference standard for the training and testing images was based on the assessment of human readers determining which were visible, only within a radiograph. Many radiologist fail to detect "occult fracture" because of the difficulty in detecting such fracture in a radiograph. These extraction methodologies could adversely influence the classification accuracy and occult fracture being assessed as a "non-fracture case". A proficient algorithm may help identify and triage studies for the radiologist to review more urgently, helping to ensure faster diagnoses.

The purpose of our study is to develop an automated deep learning system for detecting cervical spine fractures using CT a gold standard annotated by radiologists, and to evaluate the diagnostic performance inclusive of the experienced readers in detecting cervical spine fractures on radiographs.

### 2 Methodology

### 2.1 Dataset and Study Population

We use the dataset consisting of cervical spine CT scans provided by the Radiological Society of North America (RSNA). The dataset we are using is made up of roughly 3000 CT studies, from twelve locations and across six continents. Spine radiology specialists have provided annotations to indicate the presence, vertebral level and location of any cervical spine fractures. Each radiology study consists of multiple dcm files. A dcm file follows the Digital Imaging and Communications in Medicine (DICOM) format. It is the standard format used for storing medical images and related metadata. It dates back to 1983, although it has been revised many times. Out of these 3000 patient studies, 83 of these studies also contains segmentation data. Additionally, for x studies the dataset contains bounding box coordinates data. The dataset population is split into 90% for training and 10% for validation.

# 2.1.1 This is an example for third level head—subsubsection head

Sample body text. Sample body text. Sample body text. Sample body text. Sample body text.

### 3 Equations

Equations in IATEX can either be inline or on-a-line by itself ("display equations"). For inline equations use the  $\dots$  commands. E.g.: The equation  $H\psi = E\psi$  is written via the command  $H = E\psi$  is written via the command  $H = E\psi$ .

For display equations (with auto generated equation numbers) one can use the equation or align environments:

$$\|\tilde{X}(k)\|^{2} \leq \frac{\sum_{i=1}^{p} \|\tilde{Y}_{i}(k)\|^{2} + \sum_{j=1}^{q} \|\tilde{Z}_{j}(k)\|^{2}}{p+q}.$$
 (1)

where,

$$D_{\mu} = \partial_{\mu} - ig \frac{\lambda^a}{2} A^a_{\mu}$$

$$F^a_{\mu\nu} = \partial_{\mu} A^a_{\nu} - \partial_{\nu} A^a_{\mu} + g f^{abc} A^b_{\mu} A^a_{\nu}$$
(2)

Notice the use of \nonumber in the align environment at the end of each line, except the last, so as not to produce equation numbers on lines where no equation numbers are required. The \label{} command should only be used at the last line of an align environment where \nonumber is not used.

$$Y_{\infty} = \left(\frac{m}{\text{GeV}}\right)^{-3} \left[1 + \frac{3\ln(m/\text{GeV})}{15} + \frac{\ln(c_2/5)}{15}\right]$$
 (3)

The class file also supports the use of  $\mathcal{R}$ ,  $\mathcal{R}$  and  $\mathcal{R}$  produces  $\mathbb{R}$ , and  $\mathcal{R}$  produces  $\mathbb{R}$ ,  $\mathcal{R}$  and  $\mathcal{R}$  respectively (refer Subsubsection 2.1.1).

### 4 Tables

Tables can be inserted via the normal table and tabular environment. To put footnotes inside tables you should use \footnotetext[]{...} tag. The footnote appears just below the table itself (refer Tables 1 and 2). For the corresponding footnotemark use \footnotemark[...]

The input format for the above table is as follows:

```
\begin{table}[<placement-specifier>]
\begin{center}
\begin{minipage}{<preferred-table-width>}
\caption{<table-caption>}\label{<table-label>}%
\begin{tabular}{@{}llll@{}}
\toprule
Column 1 & Column 2 & Column 3 & Column 4\\
\midrule
```

Table 1 Caption text

Column 1	Column 2	Column 3	Column 4
row 1 row 2	data 1 data 4	data 2 data 5 <sup>1</sup>	data 3 data 6
row 3	data 7	data 8	data $9^2$

Source: This is an example of table footnote. This is an example of table footnote.

```
row 1 & data 1 & data 2 & data 3 \\
row 2 & data 4 & data 5\footnotemark[1] & data 6 \\
row 3 & data 7 & data 8 & data 9\footnotemark[2]\\
\botrule
\end{tabular}
\footnotetext{Source: This is an example of table footnote.
This is an example of table footnote.}
\footnotetext[1]{Example for a first table footnote.
This is an example of table footnote.}
\footnotetext[2]{Example for a second table footnote.
This is an example of table footnote.}
\end{minipage}
\end{center}
\end{table}
```

Table 2 Example of a lengthy table which is set to full textwidth

	Element 1 <sup>1</sup>		Element 2 <sup>2</sup>			
Project	Energy	$\sigma_{calc}$	$\sigma_{expt}$	Energy	$\sigma_{calc}$	$\sigma_{expt}$
Element 3 Element 4	990 A 500 A	1168 961	$1547 \pm 12$ $922 \pm 10$	780 A 900 A	1166 1268	$1239 \pm 100$ $1092 \pm 40$

Note: This is an example of table footnote. This is an example of table footnote this is an example of table footnote this is an example of table footnote.

In case of double column layout, tables which do not fit in single column width should be set to full text width. For this, you need to use \begin{table\*} ... \end{table\*} instead of \begin{table} ... \end{table} environment. Lengthy tables which do not fit in textwidth should

<sup>&</sup>lt;sup>1</sup>Example for a first table footnote. This is an example of table footnote.

<sup>&</sup>lt;sup>2</sup>Example for a second table footnote. This is an example of table footnote.

<sup>&</sup>lt;sup>1</sup>Example for a first table footnote.

 $<sup>^2{\</sup>rm Example}$  for a second table footnote.

be set as rotated table. For this, you need to use \begin{sidewaystable} ... \end{sidewaystable} instead of \begin{table\*} ... \end{table\*} environment. This environment puts tables rotated to single column width. For tables rotated to double column width, use \begin{sidewaystable\*} ... \end{sidewaystable\*}.

### 5 Figures

As per the LATEX standards you need to use eps images for LATEX compilation and pdf/jpg/png images for PDFLaTeX compilation. This is one of the major difference between LATEX and PDFLaTeX. Each image should be from a single input .eps/vector image file. Avoid using subfigures. The command for inserting images for LATEX and PDFLaTeX can be generalized. The package used to insert images in LaTeX/PDFLaTeX is the graphicx package. Figures can be inserted via the normal figure environment as shown in the below example:

```
\begin{figure}[<placement-specifier>]
\centering
\includegraphics{<eps-file>}
\caption{<figure-caption>}\label{<figure-label>}
\end{figure}
```

Fig. 1 This is a widefig. This is an example of long caption this is an example of long caption this is an example of long caption

In case of double column layout, the above format puts figure caption-s/images to single column width. To get spanned images, we need to provide \begin{figure\*} ... \end{figure\*}.

For sample purpose, we have included the width of images in the optional argument of \includegraphics tag. Please ignore this.

### 6 Algorithms, Program codes and Listings

Packages algorithm, algorithmicx and algorithms in LATEX using the format:

```
\begin{algorithm}
\caption{<alg-caption>}\label{<alg-label>}
\begin{algorithmic}[1]
```

. . .

Table 3 Tables which are too long to fit, should be written using the "sidewaystable" environment as shown here

		Element 1 <sup>1</sup>			Element <sup>2</sup>	
Projectile	Energy	$\sigma_{calc}$	$\sigma_{expt}$	Energy	$\sigma_{calc}$	$\sigma_{expt}$
Element 3	990 A	1168	$1547\pm12$	780 A	1166	$1239 \pm 100$
Element 4	500  A	961	$922 \pm 10$	900 A	1268	$1092 \pm 40$
Element 5	990 A	1168	$1547 \pm 12$	780 A	1166	$1239 \pm 100$
Element 6	500  A	961	$922 \pm 10$	900 A	1268	$1092 \pm 40$
			4			

Note: This is an example of table footnote this is an example of table footnote.  $^{1}$ This is an example of table footnote.

```
\end{algorithmic}
\end{algorithm}
```

You may refer above listed package documentations for more details before setting algorithm environment. For program codes, the "program" package is required and the command to be used is \begin{program} ... \end{program}. A fast exponentiation procedure:

```
begin
  for i := 1 to 10 step 1 do
      expt(2, i);
      newline() od
                                 Comments will be set flush to the right margin
where
proc expt(x, n) \equiv
  z := 1:
  do if n = 0 then exit fi:
      do if odd(n) then exit fi;
         comment: This is a comment statement:
         n := n/2; \ x := x * x \text{ od};
      {n > 0}:
      n := n - 1; \ z := z * x  od;
  print(z).
end
```

#### **Algorithm 1** Calculate $y = x^n$

```
Require: n > 0 \lor x \neq 0
Ensure: y = x^n
 1: u \Leftarrow 1
 2: if n < 0 then
         X \Leftarrow 1/x
         N \Leftarrow -n
 5: else
         X \Leftarrow x
 6:
         N \Leftarrow n
 8: end if
 9: while N \neq 0 do
         if N is even then
10:
              X \Leftarrow X \times X
              N \Leftarrow N/2
12:
         else[N \text{ is odd}]
13:
              y \Leftarrow y \times X
14:
              N \Leftarrow N - 1
15:
         end if
17: end while
```

Similarly, for listings, use the listings package. \begin{lstlisting} ... \end{lstlisting} is used to set environments similar to verbatim environment. Refer to the lstlisting package documentation for more details

```
for i:=maxint to 0 do
begin
{ do nothing }
end;
Write('Case_insensitive_');
Write('Pascal_keywords.');
```

### 7 Cross referencing

Environments such as figure, table, equation and align can have a label declared via the \label{#label} command. For figures and table environments use the \label{} command inside or just below the \caption{} command. You can then use the \ref{#label} command to cross-reference them. As an example, consider the label declared for Figure 1 which is \label{fig1}. To cross-reference it, use the command Figure \ref{fig1}, for which it comes up as "Figure 1".

To reference line numbers in an algorithm, consider the label declared for the line number 2 of Algorithm 1 is \label{algln2}. To cross-reference it, use the command \ref{algln2} for which it comes up as line 2 of Algorithm 1.

#### 7.1 Details on reference citations

Standard LATEX permits only numerical citations. To support both numerical and author-year citations this template uses natbib LATEX package. For style guidance please refer to the template user manual.

Here is an example for \cite{...}: [1]. Another example for \citep{...}: [7]. For author-year citation mode, \cite{...} prints Jones et al. (1990) and \citep{...} prints (Jones et al., 1990).

All cited bib entries are printed at the end of this article: [8], [9], [10], [11], [12], [13], [14], [15], [16] and [17].

### 8 Examples for theorem like environments

For theorem like environments, we require amsthm package. There are three types of predefined theorem styles exists—thmstyleone, thmstyletwo and thmstylethree

thmstyleone	Numbered, theorem head in bold font and theorem
	text in italic style
thmstyletwo	Numbered, theorem head in roman font and theorem
	text in italic style
thmstylethree	Numbered, theorem head in bold font and theorem
	text in roman style

For mathematics journals, theorem styles can be included as shown in the following examples:

**Theorem 1** (Theorem subhead) Example theorem text. Example theorem text.

Sample body text. Sample body text. Sample body text. Sample body text. Sample body text.

**Proposition 2** Example proposition text. Example proposition text.

Sample body text. Sample body text. Sample body text. Sample body text. Sample body text.

Example 1 Phasellus adipiscing semper elit. Proin fermentum massa ac quam. Sed diam turpis, molestie vitae, placerat a, molestie nec, leo. Maecenas lacinia. Nam ipsum ligula, eleifend at, accumsan nec, suscipit a, ipsum. Morbi blandit ligula feugiat magna. Nunc eleifend consequat lorem.

Sample body text. Sample body text.

Remark 1 Phasellus adipiscing semper elit. Proin fermentum massa ac quam. Sed diam turpis, molestie vitae, placerat a, molestie nec, leo. Maecenas lacinia. Nam ipsum ligula, eleifend at, accumsan nec, suscipit a, ipsum. Morbi blandit ligula feugiat magna. Nunc eleifend consequat lorem.

Sample body text. Sample body text. Sample body text. Sample body text. Sample body text.

**Definition 1** (Definition sub head) Example definition text. Example definition text.

Additionally a predefined "proof" environment is available: \begin{proof} ... \end{proof}. This prints a "Proof" head in italic font style and the "body text" in roman font style with an open square at the end of each proof environment.

*Proof* Example for proof text.  $\Box$ 

Sample body text. Sample body text.

Proof of Theorem 1 Example for proof text.  $\Box$ 

For a quote environment, use \begin{quote}...\end{quote}

Quoted text example. Aliquam porttitor quam a lacus. Praesent vel arcu ut tortor cursus volutpat. In vitae pede quis diam bibendum placerat. Fusce elementum convallis neque. Sed dolor orci, scelerisque ac, dapibus nec, ultricies ut, mi. Duis nec dui quis leo sagittis commodo.

Sample body text. Sample body text (refer Table 3).

### 9 Methods

Topical subheadings are allowed. Authors must ensure that their Methods section includes adequate experimental and characterization data necessary for others in the field to reproduce their work. Authors are encouraged to include RIIDs where appropriate.

Ethical approval declarations (only required where applicable) Any article reporting experiment/s carried out on (i) live vertebrate (or higher invertebrates), (ii) humans or (iii) human samples must include an unambiguous statement within the methods section that meets the following requirements:

- 1. Approval: a statement which confirms that all experimental protocols were approved by a named institutional and/or licensing committee. Please identify the approving body in the methods section
- 2. Accordance: a statement explicitly saying that the methods were carried out in accordance with the relevant guidelines and regulations

3. Informed consent (for experiments involving humans or human tissue samples): include a statement confirming that informed consent was obtained from all participants and/or their legal guardian/s

If your manuscript includes potentially identifying patient/participant information, or if it describes human transplantation research, or if it reports results of a clinical trial then additional information will be required. Please visit (https://www.nature.com/nature-research/editorial-policies) for Nature Portfolio journals, (https://www.springer.com/gp/authors-editors/journal-author/journal-author-helpdesk/publishing-ethics/14214) for Springer Nature journals, or (https://www.biomedcentral.com/getpublished/editorial-policies#ethics+and+consent) for BMC.

#### 10 Discussion

Discussions should be brief and focused. In some disciplines use of Discussion or 'Conclusion' is interchangeable. It is not mandatory to use both. Some journals prefer a section 'Results and Discussion' followed by a section 'Conclusion'. Please refer to Journal-level guidance for any specific requirements.

#### 11 Conclusion

Conclusions may be used to restate your hypothesis or research question, restate your major findings, explain the relevance and the added value of your work, highlight any limitations of your study, describe future directions for research and recommendations.

In some disciplines use of Discussion or 'Conclusion' is interchangeable. It is not mandatory to use both. Please refer to Journal-level guidance for any specific requirements.

**Supplementary information.** If your article has accompanying supplementary file/s please state so here.

Authors reporting data from electrophoretic gels and blots should supply the full unprocessed scans for key as part of their Supplementary information. This may be requested by the editorial team/s if it is missing.

Please refer to Journal-level guidance for any specific requirements.

**Acknowledgments.** Acknowledgments are not compulsory. Where included they should be brief. Grant or contribution numbers may be acknowledged.

Please refer to Journal-level guidance for any specific requirements.

### **Declarations**

Some journals require declarations to be submitted in a standardised format. Please check the Instructions for Authors of the journal to which you are submitting to see if you need to complete this section. If yes, your manuscript must contain the following sections under the heading 'Declarations':

- Funding
- Conflict of interest/Competing interests (check journal-specific guidelines for which heading to use)
- Ethics approval
- Consent to participate
- Consent for publication
- Availability of data and materials
- Code availability
- Authors' contributions

If any of the sections are not relevant to your manuscript, please include the heading and write 'Not applicable' for that section.

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Scientific Reports:

https://www.nature.com/srep/journal-policies/editorial-policies

BMC journals:

https://www.biomedcentral.com/getpublished/editorial-policies

### Appendix A Section title of first appendix

An appendix contains supplementary information that is not an essential part of the text itself but which may be helpful in providing a more comprehensive understanding of the research problem or it is information that is too cumbersome to be included in the body of the paper.

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