

FPGA Implementation of Parameter Optimization using Levenberg & Marquart Algorithm

Mehmet Ali Cavuslu^aand suhap sahin^b

^aKoc Information and Defence Tech., TURKEY; ^bKocaeli University Computer Engineering Department, TURKEY

ARTICLE HISTORY

Compiled January 23, 2017

ABSTRACT

.

KEYWORDS

Levenberg Marquardt; FPGA; Filter; ANN;

1. Introduction

2. Levenberg & Marquard Algorithm

Egim dusum ve Newton algoritmalarından turetilen LM algoritmasina ait parametre guncelleme islemi Eq. 1’de verilmistir. Eq. 1’de ω agirlik vektoru, I birim matris, μ kombinasyon katsayisidir. J , $[(Pxn), N]$ boyutunda Jacobian matrisini, e , $[(Pxn), 1]$ boyutunda hata vektorunu gostermektedir. P , optimize edilecek ornek sayisini, n cikis sayisini ve N optimize edilecek parametre sayisini gostermektedir (Wilamowski, Chen, & Malinowski 1999).

$$\Delta\omega = (J^T J + \mu I)J^T e \quad (1)$$

Levenberg & Marquardt algoritmasi parametre guncelleme islemlerini, tum giris ornek degerleri icin olusturdugu hata vektorunu ve Jacobian matrisini kullanarak yapmaktadir. Eq. 2’de Jacobian matrisinin elde edilmesi gosterilmektedir. Hata vektore ise Eq. 3’deki gibi elde edilir.

$$J = \begin{bmatrix} \frac{\partial e_{11}}{\partial \omega_1} & \frac{\partial e_{11}}{\partial \omega_2} & \cdots & \frac{\partial e_{11}}{\partial \omega_N} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{\partial e_{1n}}{\partial \omega_1} & \frac{\partial e_{1n}}{\partial \omega_2} & \cdots & \frac{\partial e_{1n}}{\partial \omega_N} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{\partial e_{P1}}{\partial \omega_1} & \frac{\partial e_{P1}}{\partial \omega_2} & \cdots & \frac{\partial e_{P1}}{\partial \omega_N} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{\partial e_{Pn}}{\partial \omega_1} & \frac{\partial e_{Pn}}{\partial \omega_2} & \cdots & \frac{\partial e_{Pn}}{\partial \omega_N} \end{bmatrix} \quad (2)$$

$$e = \begin{bmatrix} e_{11} \\ \cdots \\ e_{1n} \\ \cdots \\ e_{P1} \\ \cdots \\ e_{Pn} \end{bmatrix} \quad (3)$$

Eq. 1'de μ ayarlanabilir bir parametredir (Eq. 4). Eger bu parametre cok buyukse yontem egim dusum metodu gibi davranmaktadir. Eger cok kucukse Newton metodu gibi davranmaktadir ((Hashemipoor, suratgar, & Fard, 2010)).

$$\mu(n) = \begin{cases} k\mu(n-1) & E(t) > E(t-1) \\ \mu(n-1)/k & E(t) \leq E(t-1) \end{cases} \quad (4)$$

3. FPGA Implementation of Levenberg & Marquard Algorithm

FPGA tabanlı Levenberg & Marquardt Algoritması ile parametre optimizasyonu donanımsal gerçekleştirilmesi Jacobian matrisinin oluşturulması, parametrelerin güncellenmesi aşamalarından meydana gelmektedir.

3.1. *Jacobian matrix generating*

Bu çalışmada Levenberg & Marquardt algoritması kullanarak parametre optimizasyonu işlemlerinin paralel mimaride gerçekleştirilmesi amaçlanmıştır. Bu nedenle optimize edilecek parametre için ayrı RAM blokları (N) oluşturulmuştur. Her bir RAM bloğunun uzunluğu giriş örnek sayısına esittir. RAM'ların derinlikleri çalışmada 32 bit kayan noktalı sayı formatında işlem yapılacağından dolayı 32 bit olarak ayarlanmıştır (Fig. 1).

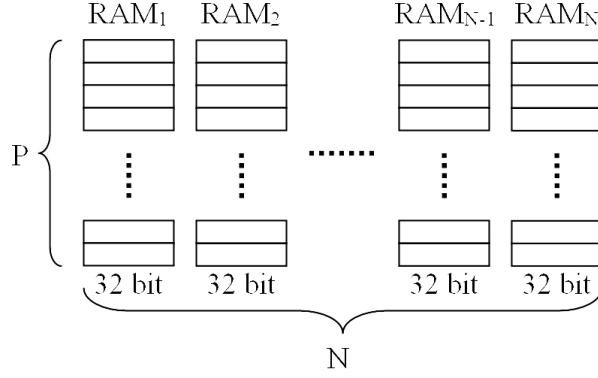


Figure 1. swarm updating block schema

3.2. *Multiplication of transpose Jacobian matrix and Jacobian matrix*

Parametrelerin guncellemesi isleminde (2.19)daki esitlik adim adim uygulanmaktadır. Jacobian matrisinin olusturulmasi sonrasinda gerceklestirilen devrik Jacobian matris carpimi ile Jacobian matrisi carpimi sonucunda $N \times N$ boyotunda matrisi elde edilir. slem sonuclarinin saklanmasi icin cikista elde edilecek matris boyutlari referans alinarak N uzunlugunda ve 32 bit derilikte N adet RAM blogu olusturulmustur (Fig. 2). her parametre degerlerinin farkli RAM'de saklanmasi ile islem yapilacak satirdaki tum degerler ayni anda okunabilmektedir ve islemler ayni anda gerceklenerek zamandan kazanim saglanmaktadır. Parallelestirme islemi yapilmadan N^2P dongude gerceklestirilen carpma islemi NP dongude gerceklestirilmistir.

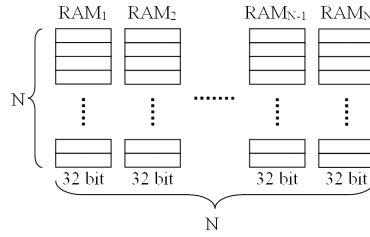


Figure 2. Matris carpimi sonucunu saklamak icin olusturulan blok ram yapisi

Donanimsal gerceklemede birinci adimda ilk olarak, Jacobian matrisinde her parametre icin olusturulan blok RAMlardan degerler sirasiyla okunmaktadır. 2. adimda bu degerler, arasindan carpma isleminde kullanilacak olan $J(k, m)$ degeri secilmektedir. 3. adimda secilen bu deger, 1. adimda okudugumuz degerlerle carpilmaktadir. 4. Adimda, 3. adimda elde edilen carpma degeri bir onceki k degerinde elde edilen toplam degeri ile toplanmaktadır. Bu toplam degeri $k = 0$ icin 0 olmaktadır. 5. adimda k degeri bir artirilmakta eger k degeri P degerinden kucukse 1. adima gecilmekte aksi takdirde 6. adima gecilmektedir (Fig. 3).

6. adimda 4. adimda elde edilen toplam degeri carpim degerlerini tutmak icin olusturulan RAMlara yazilmektedir. μI degerinin matris carpimina olan etkisi sadece matris kosegenlerine μ degerini eklenmesi ile elde edilebilmektedir. Bu nedenle 7. adimda matrisin (m, m) kosegen degeri bulunmakta, 8. Adimda ise bu deger RAMa yazilmektedir. 9. adimda m degeri bir artirilmaktadır. Bu deger N degerinden kucuk olursa 1. adima tekrar donulur. Aksi takdirde islem sonlandirilir (Fig. 4).

Matris carpimi isleminde RAMa yazilan kosegen degerleri 1. adimda RAMdan okun-

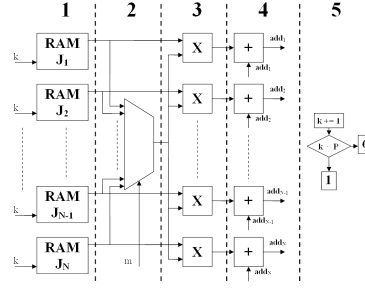


Figure 3. Matris carpimi sonucunu saklamak icin olusturulan blok ram yapisi

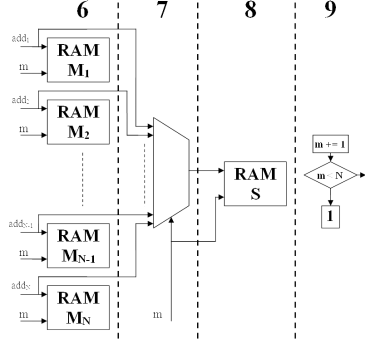


Figure 4. Matris carpimi sonucunu saklamak icin olusturulan blok ram yapisi

maktadır. 2. adimda okunan deger, ilgili kosegen degerine yonlendirilir. 3. adimda da bu deger μ parametresi eklenir. 4. asamada elde edilen sonuclar RAMin m . adresine yazilmaktadir. 5. adimda ise m degeri bir artirilmaktadir. Bu deger N degerinden kucuk olursa 1. adima tekrar donulur. Aksi takdirde islem sonlandirilir (Fig. 5).

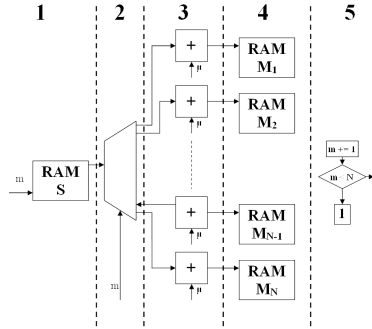


Figure 5. Matris carpimi sonucunu saklamak icin olusturulan blok ram yapisi

3.3. Inverse Matrix Calculation

Literatürde matrisin tersini almak için adjoint, LU, QR, Hermitian, Analitik, Block-wise, Gauss-Jordan yok etme yöntemleri önerilmiştir. Bu çalışmada Gauss-Jordan yok etme yöntemi kullanılarak matris boyutu sınırlaması olmadan donanımsal gerçekleştirilmesi üzerinde çalışılmıştır.

Matrisin tersini alma işleminde 1. asamada ilk olarak bir önceki asamada elde ettiğimiz ve RAM_M larda sakladığımız μ parametresi eklenmiş carpim degerleri ve

başlangıçta birim matris olarak oluşturulan RAM_J lerden m . adresteki değerler okunmaktadır. 2. aşamada m . RAM_M deki deger secilmektedir. 3. aşamada, 1. aşamada okunan tüm degerler 2. aşamada elde edilen degere bolunmaktadır. Bölme sonuçları 4. aşamada tekrar RAM_M ve RAM_J lerde m . adreslerdeki yerlerine yazılmaktadır (Fig. 6).

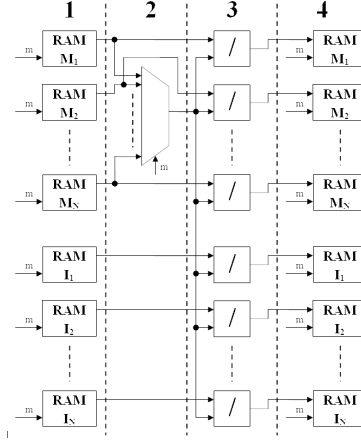


Figure 6. Matris carpimi sonucunu saklamak için oluşturulan blok ram yapisi

5. adımda x degerinin m degerine esit olup olmadigi kontrol edilmektedir. Eger esit ise x degeri 1 artırılmak üzere 13. adima gecilmektedir. Aksi takdirde 6. adima gecilmektedir. 6. adımda carpim degerlerinin ve ters (invers) degerlerinin tutulduğu matris degerleri RAMlardan x . degerler okunmaktadır. 7. adımda ise carpim degerlerinin tutulduğu RAMlardan okunan degerlerden m . RAMa ait deger indeks degeri olarak secilmektedir. 8. adımda ise RAMlardan okunan tüm degerler hafızada tutulmaktadır (Fig. 7).

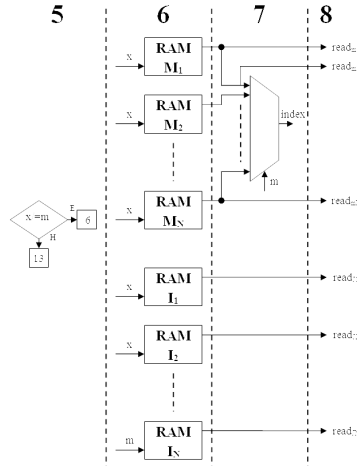


Figure 7. Matris carpimi sonucunu saklamak için oluşturulan blok ram yapisi

9. adımda ise carpim degerlerinin ve tersinin degerlerinin tutulduğu matris degerleri RAMlardan x . degerler okunmaktadır. 10. Adımda okunan bu degerler indeks degeri ile carpılmaktadır. 11. adımda, 8. adımda hafızada sakladığımız bu degerlerden 10 adımda elde edilen carpma degerleri cikartılmaktadır. 12. adımda ise cikarma islemi sonucu RAM_M ve RAM_J lerdeki x . yerlerine yazılmaktadır. 13. adımda x degeri 1

artirilmektedir. x degeri parametre sayisindan az ise 5. adima donulur aksi takdirde 14. adima gecilir. 14. Adimda ise m degeri 1 artirilir. Eger bu deger parametre sayisindan kucuk ise 1. Adima donulur aksi takdirde islem sonlandirilir (Fig. 8).

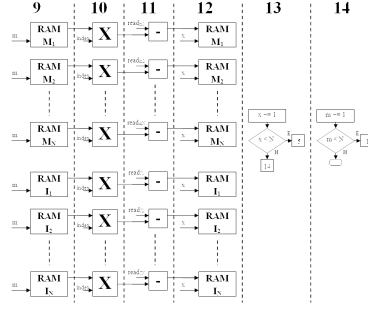


Figure 8. Matris carpimi sonucunu saklamak icin olusturulan blok ram yapisi

3.4. *Matris tersi ile devrik Jacobian matrisinin ve hata matrisinin carpimi*

1. adimda ters matris deerlerinin tutulduu RAMlardan m . deerler okunmaktadır. 2. asamada ise Jacobian matris parametrelerinin tutulduu RAMlardan x . deerler okunmaktadır. 3. asamada 1. ve 2. asamada okunan deerler 3. Asamada vektir carpimi islemine tabi tutulmaktadır. 4. asamada ise vektir carpiminin sonucu x . giris deerleri icin elde edilen hata deerleri ile carpilmektedir. 5. adimda carpim sonucu bir nceki adimda elde edilen carpim sonuc deerlerine eklenir. 6. adimda x deerleri 1 artirilmektedir. x deerleri rnek sayisindan az ise 2. adima donulur aksi takdirde 7. adima gecilir. 7. adimda tm giris rnekleri icin hata ile matris carpim sonuclarinin toplami m . parametreye ait gncelleme deerleri olarak saklanmaktadır. 8. adimda m . deerleri 1 artirilir. Eer bu deer parametre sayisindan kck ise 1. Adima dnlr aksi takdirde islem sonlandirilir (Fig. 9).

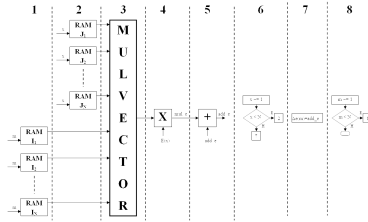


Figure 9. Matris carpimi sonucunu saklamak icin olusturulan blok ram yapisi

4. FIR Filter Parameter Optimization

5. ANN Training

YSAnn eitiminin Levenberg & Marquardt Algoritmas ile FPGAda donanmsal gereklenmesi Jacobian matrisinin oluturulma islemi Eq. 5 'de gsterilmitir (Fig. 10).

$$J = \begin{bmatrix} \Delta\omega_{11}^1 & \dots & \Delta\omega_{1q}^1 & \dots & \Delta\omega_{m1}^1 & \dots & \Delta\omega_{mq}^1 & \Delta b_1^1 & \dots & \Delta b_q^1 & \dots \end{bmatrix} \quad (5)$$

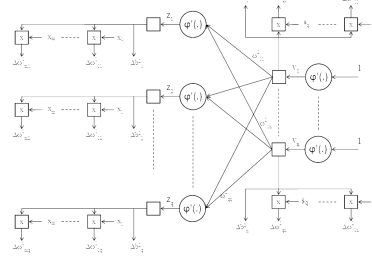


Figure 10. Matris carpimi sonucunu saklamak icin olusturulan blok ram yapisi

5.1. *Title, authors' names, affiliations, abstracts and article types*

The title should be generated at the beginning of your article using the `\maketitle` command. In the final version the author name(s) and affiliation(s) must be followed immediately by `\maketitle` as shown below in order for them to be displayed in your PDF document. To prepare an anonymous version for double-blind peer review, you can put the `\maketitle` between the `\title` and the `\author` in order to hide the author name(s) and affiliation(s) temporarily. Next you should include the abstract if your article has one, enclosed within an `abstract` environment. The `\articletype` command is also provided as an *optional* element which should only be included if your article actually needs it. For example, the titles for this document begin as follows:

```
\articletype{ARTICLE TEMPLATE}
```

```
\title{Taylor \& Francis \LaTeX\ template for authors (\textsf{Interact}
layout + American Psychological Association reference style)}
```

```
\author{
\name{A.~N. Author\textsuperscript{a}\thanks{CONTACT A.~N. Author.
Email: latex.helpdesk@tandf.co.uk} and John smith\textsuperscript{b}}
\affil{\textsuperscript{a}Taylor \& Francis, 4 Park square, Milton
Park, Abingdon, UK; \textsuperscript{b}Institut f\"{u}r Informatik,
Albert-Ludwigs-Universit\"{a}t, Freiburg, Germany} }
```

```
\maketitle
```

```
\begin{abstract}
```

This template is for authors who are preparing a manuscript for a Taylor \& Francis journal using the `\LaTeX\` document preparation system and the `\texttt{interact}` class file, which is available via selected journals' home pages on the Taylor \& Francis website.

```
\end{abstract}
```

An additional abstract in another language (preceded by a translation of the article title) may be included within the `abstract` environment if required.

A graphical abstract may also be included if required. Within the `abstract` environment you can include the code

```
\\resizebox{25pc}{!}{\includegraphics{abstract.eps}}
```

where the graphical abstract is to appear, where `abstract.eps` is the name of the file containing the graphic (note that `25pc` is the recommended maximum width, expressed in pica, for the graphical abstract in your manuscript).

5.2. *Abbreviations*

A list of abbreviations may be included if required, enclosed within an `abbreviations` environment, i.e. `\begin{abbreviations}... \end{abbreviations}`, immediately following the `abstract` environment.

5.3. *Keywords*

A list of keywords may be included if required, enclosed within a `keywords` environment, i.e. `\begin{keywords}... \end{keywords}`. Additional keywords in other languages (preceded by a translation of the word ‘keywords’) may also be included within the `keywords` environment if required.

5.4. *subject classification codes*

AMs, JEL or PACs classification codes may be included if required. The `interact` class file provides an `amscodes` environment, i.e. `\begin{amscodes}... \end{amscodes}`, a `jelcodes` environment, i.e. `\begin{jelcodes}... \end{jelcodes}`, and a `pacscodes` environment, i.e. `\begin{pacscodes}... \end{pacscodes}` to assist with this.

6. some guidelines for using the standard features of L^AT_EX

6.1. *sections*

The `Interact` layout style allows for five levels of section heading, all of which are provided in the `interact` class file using the standard L^AT_EX commands `\section`, `\subsection`, `\subsubsection`, `\paragraph` and `\subparagraph`. Numbering will be automatically generated for all these headings by default.

6.2. *Lists*

Numbered lists are produced using the `enumerate` environment, which will number each list item with arabic numerals by default. For example,

- (1) first item
- (2) second item
- (3) third item

was produced by

```
\begin{enumerate}  
  \item first item
```



```

\item second item
\item third item
\end{enumerate}

```

Alternative numbering styles can be achieved by inserting an optional argument in square brackets to each `item`, e.g. `\item[(i)] first item` to create a list numbered with roman numerals at level one.

Bulleted lists are produced using the `itemize` environment. For example,

- First bulleted item
- second bulleted item
- Third bulleted item

was produced by

```

\begin{itemize}
\item First bulleted item
\item second bulleted item
\item Third bulleted item
\end{itemize}

```

6.3. *Figures*

The `interact` class file will deal with positioning your figures in the same way as standard L^AT_EX. It should not normally be necessary to use the optional `[htb]` location specifiers of the `figure` environment in your manuscript, although the `[p]` option – i.e. `\begin{figure}[p]` – is useful if you are asked to separate figures from the text.

Figure captions should appear below the figure itself, therefore the `\caption` command should appear after the figure. For example, Figure 11 with caption and sub-captions is produced using the following commands:

```

\begin{figure}
\centering
\subfigure[An example of an individual figure sub-caption.]{
\resizebox*{5cm}{!}{\includegraphics{graph1.eps}}}\hspace{5pt}
\subfigure[A slightly shorter sub-caption.]{
\resizebox*{5cm}{!}{\includegraphics{graph2.eps}}}
\caption{Example of a two-part figure with individual sub-captions
showing that captions are flush left and justified if greater
than one line of text.} \label{sample-figure}
\end{figure}

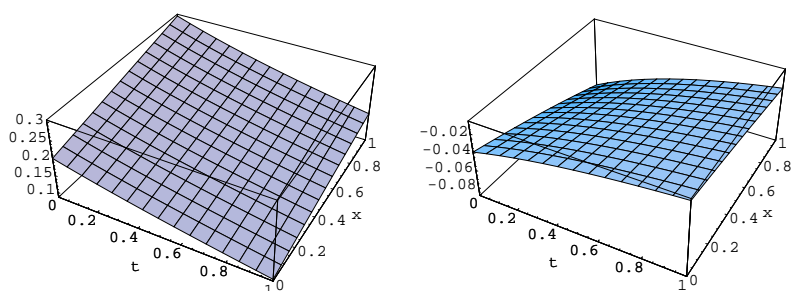
```

To ensure that figures are correctly numbered automatically, the `\label` command should be included just after the `\caption` command, or in its argument.

The `\subfigure` command requires `subfigure.sty`, which is called in the preamble of the `interactapasample.tex` file (in order to allow your choice of an alternative package if preferred) and included in the `Interact LATEX` bundle for convenience. Please supply any additional figure macros you use with your article in the preamble of your `.tex` file, before `\begin{document}`.

The source files of any figures will be required when the final, revised version of a manuscript is submitted. Authors should ensure that these are suitable (in terms of lettering size, etc.) for the reductions they envisage.

The `epstopdf` package can be used to incorporate encapsulated Postscript (`.eps`)



(a) An example of an individual figure sub-caption. (b) A slightly shorter sub-caption.

Figure 11. Example of a two-part figure with individual sub-captions showing that captions are flush left and justified if greater than one line of text.

Table 1. Example of a table showing that its caption is as wide as the table itself and justified.

Class	Type					
	One	Two	Three	Four	Five	six
Alpha ^a	A1	A2	A3	A4	A5	A6
Beta	B2	B2	B3	B4	B5	B6
Gamma	C2	C2	C3	C4	C5	C6

^aThis footnote shows how to include footnotes to a table if required.

illustrations when using PDF \LaTeX , etc. Please provide the original .eps source files rather than the generated PDF images of those illustrations for production purposes.

6.4. Tables

The `interact` class file will deal with positioning your tables in the same way as standard \LaTeX . It should not normally be necessary to use the optional `[htb]` location specifiers of the `table` environment in your manuscript, although the `[p]` option – i.e. `\begin{table}[p]` – is useful if you are asked to separate tables from the text.

The `tabular` environment can be used as illustrated here to produce tables with single horizontal rules at the head, foot and elsewhere as appropriate. The table caption appears above the body of the table in the `Interact` layout style, therefore the `\tbl` command should be used before the body of the table. For example, Table 1 is produced using the following commands:

```
\begin{table}
\tbl{Example of a table showing that its caption is as wide as
the table itself and justified.}
{\begin{tabular}{lcccccc} \toprule
& \multicolumn{2}{l}{Type} & \midrule{2-7}
Class & One & Two & Three & Four & Five & six & \midrule
Alpha\textsuperscript{a} & A1 & A2 & A3 & A4 & A5 & A6 & \midrule
Beta & B2 & B2 & B3 & B4 & B5 & B6 & \midrule
Gamma & C2 & C2 & C3 & C4 & C5 & C6 & \bottomrule
```

```

\end{tabular}}
\tabnote{\textsuperscript{a}This footnote shows how to include
  footnotes to a table if required.}
\label{sample-table}
\end{table}

```

To ensure that tables are correctly numbered automatically, the `\label` command should be included just before `\end{table}`.

The `\toprule`, `\midrule`, `\bottomrule` and `\cmidrule` commands require `booktabs.sty`, which is called by the `interact` class file and included in the `Interact` L^AT_EX bundle for convenience. Tables produced using the standard commands of the `tabular` environment are also compatible with the `interact` class file.

6.5. *Landscape pages*

If a figure or table is too wide to fit the page it will need to be rotated, along with its caption, through 90° anticlockwise. Landscape figures and tables can be produced using the `rotating` package, which is called by the `interact` class file. The following commands (for example) can be used to produce such pages.

```

\setcounter{figure}{1}
\begin{sidewaysfigure}
\centerline{\epsfbox{figname.eps}}
\caption{Example landscape figure caption.}
\label{landfig}
\end{sidewaysfigure}

\setcounter{table}{1}
\begin{sidewaystable}
\tbl{Example landscape table caption.}
{\begin{tabular}{@{}l111lc11}
.
.
.
\end{tabular}}\label{landtab}
\end{sidewaystable}

```

Before any such float environment, use the `\setcounter` command as above to fix the numbering of the caption (the value of the counter being the number given to the preceding figure or table). subsequent captions will then be automatically renumbered accordingly. The `\epsfbox` command requires `epsfig.sty`, which is called by the `interact` class file and is also included in the `Interact` L^AT_EX bundle for convenience.

6.6. *Theorem-like structures*

A predefined `proof` environment is provided by the `amsthm` package (which is called by the `interact` class file), as follows:

Proof. More recent algorithms for solving the semidefinite programming relaxation are particularly efficient, because they explore the structure of the MAX-CUT problem. □

This was produced by simply typing:

```
\begin{proof}
More recent algorithms for solving the semidefinite programming
relaxation are particularly efficient, because they explore the
structure of the MAX-CUT problem.
\end{proof}
```

Other theorem-like environments (theorem, definition, remark, etc.) need to be defined as required, e.g. using `\newtheorem{theorem}{Theorem}` in the preamble of your .tex file (see the preamble of `interactapasample.tex` for more examples). You can define the numbering scheme for these structures however suits your article best. Please note that the format of the text in these environments may be changed if necessary to match the style of individual journals by the typesetter during preparation of the proofs.

6.7. Mathematics

6.7.1. Displayed mathematics

The `interact` class file will set displayed mathematical formulas centred on the page without equation numbers if you use the `displaymath` environment or the equivalent `\[...\]` construction. For example, the equation

$$\hat{\theta}_{w_i} = \hat{\theta}(s(t, \mathcal{U}_{w_i}))$$

was typeset using the commands

```
\[
\hat{\theta}_{w_i} = \hat{\theta}(s(t, \mathcal{U}_{w_i}))
\]
```

For those of your equations that you wish to be automatically numbered sequentially throughout the text, use the `equation` environment, e.g.

$$\hat{\theta}_{w_i} = \hat{\theta}(s(t, \mathcal{U}_{w_i})) \tag{6}$$

was typeset using the commands

```
\begin{equation}
\hat{\theta}_{w_i} = \hat{\theta}(s(t, \mathcal{U}_{w_i}))
\end{equation}
```

Part numbers for sets of equations may be generated using the `subequations` environment, e.g.

$$\varepsilon \rho w_{tt}(s, t) = N[w_s(s, t), w_{st}(s, t)]_s, \tag{7a}$$

$$w_{tt}(1, t) + N[w_s(1, t), w_{st}(1, t)] = 0, \tag{7b}$$

which was generated using the commands

```
\begin{subequations} \label{subeqnexample}
\begin{equation}
```

```

\varepsilon \rho w_{tt}(s,t)
= N[w_s(s,t),w_{st}(s,t)]_s,
\label{subeqnpart}
\end{equation}
\begin{equation}
w_{tt}(1,t)+N[w_s(1,t),w_{st}(1,t)] = 0,
\end{equation}
\end{subequations}

```

This is made possible by the `amsmath` package, which is called by the class file. If you put the `\label{}` just after the `\begin{subequations}` line, references will be to the collection of equations, ‘(7)’ in the example above. Or, like the example code above, you can reference each equation individually – e.g. ‘(7a)’.

Displayed mathematics should be given end-of-line punctuation appropriate to the running text sentence of which it forms a part, if required.

6.7.2. Math fonts

6.7.2.1. *superscripts and subscripts.* superscripts and subscripts will automatically come out in the correct size in a math environment (i.e. enclosed by ‘\$’ delimiters in running text, or within `\[...\]` or the ‘`equation`’ environment for displayed equations). sub/superscripts that are physical variables should be italic, whereas those that are labels should be roman (e.g. C_p , T_{eff}). If the subscripts or superscripts need to be other than italic, they must be coded individually.

6.7.2.2. *Upright Greek characters and the upright partial derivative sign.* Upright lowercase Greek characters can be obtained by inserting the letter ‘u’ in the control code for the character, e.g. `\umu` and `\upi` produce μ (used, for example, in the symbol for the unit microns – μm) and π (the ratio of the circumference of a circle to its diameter). similarly, the control code for the upright partial derivative ∂ is `\upartial`. Bold lowercase as well as uppercase Greek characters can be obtained by `\bm \gamma`, for example, which gives γ , and `\bm \Gamma`, which gives Γ .

Acknowledgement(s)

An unnumbered section, e.g. `\section*{Acknowledgements}`, may be used for thanks, etc. if required and included *in the non-anonymous version* before any Notes or References.

Disclosure statement

An unnumbered section, e.g. `\section*{Disclosure statement}`, may be used to declare any potential conflict of interest and included *in the non-anonymous version* before any Notes or References, after any Acknowledgements and before any Funding information.

Funding

An unnumbered section, e.g. `\section*{Funding}`, may be used for grant details, etc. if required and included *in the non-anonymous version* before any Notes or References.

Notes on contributor(s)

An unnumbered section, e.g. `\section*{Notes on contributors}`, may be included *in the non-anonymous version* if required. A photograph may be added if requested.

Notes

An unnumbered ‘Notes’ section may be included before the References (if using the `endnotes` package, use the command `\theendnotes` where the notes are to appear, instead of creating a `\section`).

7. References

7.1. *References cited in the text*

References should be cited in accordance with American Psychological Association (APA) style, i.e. in alphabetical order separated by semicolons, e.g. ‘(Wilamowski, 1977; Greenfield & Yan, 2006; Piaget, 1988)’ or ‘...see smith (1985, p. 75)’. If there are two authors with the same surname, use the first initials with the surnames, e.g. ‘(I. Light, 2006; M. A. Light & Light, 2008)’. If there are three to five authors, list all the authors in the first citation, e.g. ‘(Ganster, schaubroeck, sime, & Mayes, 1991)’. In subsequent citations, use only the first author’s surname followed by et al., e.g. ‘(Ganster et al., 1991)’. For six or more authors, cite the first author’s name followed by et al. For two or more sources by the same author(s) in the same year, use lower-case letters (a, b, c, ...) with the year to order the entries in the reference list and use these lower-case letters with the year in the in-text citations, e.g. ‘(Green, 1981a,b)’. For further details on this reference style, see the Instructions for Authors on the Taylor & Francis website.

Each bibliographic entry has a key, which is assigned by the author and used to refer to that entry in the text. In this document, the key `Nas93` in the citation form `\citep{Nas93}` produces ‘(Nash, 1993)’, and the keys `Koc59`, `Han04` and `Cla08` in the citation form `\citep{Koc59,Han04,Cla08}` produce ‘(Clay, 2008; Haney & Wiener, 2004; Koch, 1959-1963)’. The citation `\citep{Cha08}` produces ‘(Chamberlin, Novotney, Packard, & Price, 2008)’ where the citation first appears in the text, and ‘(Chamberlin et al., 2008)’ in any subsequent citation. The appropriate citation style for different situations can be obtained, for example, by `\citet{Ovi95}` for ‘Oviedo (1995)’, `\citealp{MPW08}` for ‘Marshall-Pescini & Whiten, 2008’, and `\citealt{sch93}` for ‘schwartz 1993’. Citation of the year alone may be produced by `\citeyear{sch00}`, i.e. ‘2000’, or `\citeyearpar{Gra05}`, i.e. ‘(2005)’, or of the author(s) alone by `\citeauthor{Rit74}`, i.e. ‘Ritzmann’. Optional notes may be included at the beginning and/or end of a citation by the use of square brackets, e.g. `\citep[p.~31]{Hay08}` produces ‘(Haybron, 2008, p. 31)’;

`\citep[see][pp. ~73–77]{PI51}` produces ‘(see Piaget & Inhelder, 1951, pp. 73–77)’; `\citep[e.g.]{Fel181}` produces ‘(e.g. Feller, 1981)’. A ‘plain’ `\cite` command will produce the same results as a `\citet`, i.e. `\cite{BriIP}` will produce ‘Briscoe (in press)’.

7.2. The list of references

References should be listed at the end of the main text in alphabetical order, then chronologically (earliest first), with full page ranges (where appropriate) and issue numbers (for journals paginated by issue). If a reference has more than seven named authors, list the first six, followed by an ellipsis (...), then the last author. The following list shows some sample references prepared in American Psychological Association style.

References

- Wilamowski, B., Chen, Y., & Malinowski, A. (1999). Efficient algorithm for training neural networks with one hidden layer. *in Proceedings of the International Joint Conference on Neural Networks*, 3, 1725–1728.
- Hashemipoor, s. s., suratgar, A. A., & Fard, A. (2010). Designing a Robust MEMs AC Voltage Reference source Using Artificial Neural Network. *Australian Journal of Basic and Applied sciences*, 4(6), 1183–1189.
- American Psychological Association. (2010). *Publication manual of the American Psychological Association* (6th ed.). Washington, DC: Author.
- Bandura, A. J. (1977). *social learning theory*. Englewood Cliffs, NJ: Prentice Hall.
- Briscoe, R. (in press). Egocentric spatial representation in action and perception. *Philosophy and Phenomenological Research*. Retrieved from <http://cogprints.org/5780/1/ECsRAP.F07.pdf>
- Chamberlin, J., Novotney, A., Packard, E., & Price, M. (2008, May). Enhancing worker well-being: Occupational health psychologists convene to share their research on work, stress, and health. *Monitor on Psychology*, 39(5), 26–29.
- Clay, R. (2008, June). science vs. ideology: Psychologists fight back about the misuse of research. *Monitor on Psychology*, 39(6). Retrieved from <http://www.apa.org/monitor/>
- Feller, B. A. (1981). *Health characteristics of persons with chronic activity limitation, United states, 1979* (Tech. Rep. No. VHs-sER10/137). Hyattsville, MD: National Center for Health statistics (Us). (Available from: NTIs, springfield, VA; PB88-228622)
- Ganster, D. C., schaubroeck, J., sime, W. E., & Mayes, B. T. (1991). The nomological validity of the Type A personality among employed adults [Monograph]. *Journal of Applied Psychology*, 76, 143–168.
- Graham, G. (2005). Behaviorism. In E. N. Zalta (ed.), *The stanford encyclopedia of philosophy* (Fall 2007 ed.). Retrieved from <http://plato.stanford.edu/entries/behaviorism>
- Greenfield, P., & Yan, Z. (Eds.). (2006). Children, adolescents, and the Internet [special section]. *Developmental Psychology*, 42, 391–458.
- Haney, C., & Wiener, R. L. (Eds.). (2004). Capital punishment in the United states [special issue]. *Psychology, Public Policy, and Law*, 10(4).
- Haybron, D. M. (2008). Philosophy and the science of subjective well-being. In M. Eid & R. J. Larsen (Eds.), *The science of subjective well-being* (pp. 17–43). New York, NY: Guilford Press.
- Koch, s. (Ed.). (1959–1963). *Psychology: A study of science* (Vols. 1–6). New York, NY: McGraw-Hill.

- Light, I. (2006). *Deflecting immigration: Networks, markets, and regulation in Los Angeles*. New York, NY: Russell sage Foundation.
- Light, M. A., & Light, I. H. (2008). The geographic expansion of Mexican immigration in the United states and its applications for local law enforcement. *Law Enforcement Executive Forum Journal*, 8(1), 73–82.
- Marshall-Pescini, s., & Whiten, A. (2008). social learning of nut-cracking behavior in East African sanctuary-living chimpanzees (*Pan troglodytes schweinfurthii*) [supplemental material]. *Journal of Comparative Psychology*, 122, 186–194.
- Nash, M. (1993). Malay. In P. Hockings (Ed.), *Encyclopedia of world cultures* (Vol. 5, pp. 174–176). New York, NY: G. K. Hall.
- Oviedo, s. (1995). *Adolescent pregnancy: Voices heard in the everyday lives of pregnant teenagers* (Master's thesis). University of North Texas, Denton, TX.
- Piaget, J. (1988). Extracts from Piaget's theory (G. Gellerier & J. Langer, Trans.). In K. Richardson & s. sheldon (Eds.), *Cognitive development to adolescence: A reader* (pp. 3–18). Hillsdale, NJ: Erlbaum. (Reprinted from *Manual of child psychology*, pp. 703–732, by P. H. Mussen, Ed., 1970, New York, NY: Wiley)
- Piaget, J., & Inhelder, B. (1951). *La genèse de l'idée de hasard chez l'enfant* [The origin of the idea of chance in the child]. Paris: Presses Universitaires de France.
- Ritzmann, R. E. (1974). *The snapping mechanism of Alpheid shrimp* (Doctoral dissertation). University of Virginia, Charlottesville, VA.
- schatz, B. R. (2000, November 17). Learning by text or context? [Review of the book *The social life of information*, by J. s. Brown & P. Duguid]. *science*, 290, 1304.
- schwartz, J. (1993, september 30). Obesity affects economic, social status. *The Washington Post*, pp. A1, A4.

This was produced by typing:

```
\begin{thebibliography}{}
\bibitem[American Psychological Association(2010)]{APA10}
American Psychological Association. (2010). \emph {Publication manual
of the American Psychological Association} (6th ed.). Washington, DC:
Author.

\bibitem[Bandura(1977)]{Ban77}
Bandura, A.~J. (1977). \emph{social learning theory}. Englewood Cliffs,
NJ: Prentice Hall.

\bibitem[Briscoe(in press)]{BriIP}
Briscoe, R. (in press). {Egocentric spatial representation in action
and perception}. \emph{Philosophy and Phenomenological Research}.
Retrieved from http://cogprints.org/5780/1/ECsRAP.F07.pdf

\bibitem[Chamberlin et al.(2008)Chamberlin, Novotney, Packard, \& Price]{Cha08}
Chamberlin, J., Novotney, A., Packard, E., \& Price, M. (2008, May).
Enhancing worker well-being: Occupational health psychologists convene
to share their research on work, stress, and health. \emph{Monitor on
Psychology}, \emph{39}(5), 26--29.

\bibitem[Clay(2008)]{Cla08}
Clay, R. (2008, June). science vs. ideology: Psychologists fight back
about the misuse of research. \emph{Monitor on Psychology},
\emph{39}(6). Retrieved from http://www.apa.org/monitor/
```


\bibitem[Feller(1981)]{Fel81}

Feller, B.~A. (1981). \emph{Health characteristics of persons with chronic activity limitation, United states, 1979} (Tech. Rep. No. VHS-sER10/137). Hyattsville, MD: National Center for Health statistics (Us). (Available from: NTIs, springfield, VA; PB88-228622)

\bibitem[Ganster et al.(1991)Ganster, schaubroeck, sime, \& Mayes]{GssM91}

Ganster, D.~C., schaubroeck, J., sime, W.~E., \& Mayes, B.~T. (1991). The nomological validity of the Type A personality among employed adults [Monograph]. \emph{Journal of Applied Psychology}, \emph{76}, 143--168.

\bibitem[Graham(2005)]{Gra05}

Graham, G. (2005). Behaviorism. In E.~N. Zalta (ed.), \emph{The stanford encyclopedia of philosophy} (Fall 2007 ed.). Retrieved from <http://plato.stanford.edu/entries/behaviorism>

\bibitem[Greenfield \& Yan(2006)]{Gre06}

Greenfield, P., \& Yan, Z. (Eds.). (2006). Children, adolescents, and the Internet [special section]. \emph{Developmental Psychology}, \emph{42}, 391--458.

\bibitem[Haney \& Wiener(2004)]{Han04}

Haney, C., \& Wiener, R.~L. (Eds.). (2004). Capital punishment in the United states [special issue]. \emph{Psychology, Public Policy, and Law}, \emph{10}(4).

\bibitem[Haybron(2008)]{Hay08}

Haybron, D.~M. (2008). Philosophy and the science of subjective well-being. In M. Eid \& R.~J. Larsen (Eds.), \emph{The science of subjective well-being} (pp. 17--43). New York, NY: Guilford Press.

\bibitem[Koch(1959-1963)]{Koc59}

Koch, s. (Ed.). (1959--1963). \emph{Psychology: A study of science} (Vols.~1--6). New York, NY: McGraw-Hill.

\bibitem[I. Light(2006)]{Lig06}

Light, I. (2006). \emph{Deflecting immigration: Networks, markets, and regulation in Los Angeles}. New York, NY: Russell sage Foundation.

\bibitem[M.~A. Light \& Light(2008)]{Lig08}

Light, M.~A., \& Light, I.~H. (2008). The geographic expansion of Mexican immigration in the United states and its applications for local law enforcement. \emph{Law Enforcement Executive Forum Journal}, \emph{8}(1), 73--82.

\bibitem[Marshall-Pescini \& Whiten(2008)]{MPW08}

Marshall-Pescini, s., \& Whiten, A. (2008). social learning of nut-

cracking behavior in East African sanctuary-living chimpanzees
 (\emph{Pan troglodytes schweinfurthii}) [supplemental material].
 \emph{Journal of Comparative Psychology}, \emph{122}, 186--194.

\bibitem[Nash(1993)]{Nas93}
 Nash, M. (1993). Malay. In P.~Hockings (Ed.), \emph{Encyclopedia of
 world cultures} (Vol.~5, pp.~174--176). New York, NY: G.~K. Hall.

\bibitem[Oviedo(1995)]{Ovi95}
 Oviedo, s. (1995). \emph{Adolescent pregnancy: Voices heard in the
 everyday lives of pregnant teenagers} (Master's thesis). University
 of North Texas, Denton, TX.

\bibitem[Piaget(1988)]{Pia88}
 Piaget, J. (1988). Extracts from Piaget's theory (G.~Gellerier \&
 J.~Langer, Trans.). In K.~Richardson \& s.~sheldon (Eds.),
 \emph{Cognitive development to adolescence: A reader} (pp. 3--18).
 Hillsdale, NJ: Erlbaum. (Reprinted from \emph{Manual of child
 psychology}, pp. 703--732, by P.~H. Mussen, Ed., 1970, New York,
 NY: Wiley)

\bibitem[Piaget \& Inhelder(1951)]{PI51}
 Piaget, J., \& Inhelder, B. (1951). \emph{La gen{\`e}se de l'id{\`e}
 de hasard chez l'enfant} [The origin of the idea of chance in the
 child]. Paris: Presses Universitaires de France.

\bibitem[Ritzmann(1974)]{Rit74}
 Ritzmann, R.~E. (1974). \emph{The snapping mechanism of \emph{Alpheid}
 shrimp} (Doctoral dissertation). University of Virginia,
 Charlottesville, VA.

\bibitem[schatz(2000)]{sch00}
 schatz, B.~R. (2000, November 17). Learning by text or context?
 [Review of the book \emph{The social life of information}, by J.~s.
 Brown \& P.~Duguid]. \emph{science}, \emph{290}, 1304.

\bibitem[schwartz(1993)]{sch93}
 schwartz, J. (1993, september 30). Obesity affects economic, social
 status. \emph{The Washington Post}, pp.~A1, A4.

\end{thebibliography}

Each entry takes the form:

\bibitem[short list of authors' surnames(date of publication)long list
 of authors' surnames]{key}
 Bibliography entry

where 'long list of authors' surnames' is the *optional* 'long' list of three, four
 or five names which enables them all to appear where the `\bibitem` is first cited in
 the text (if the long list is missing, the short list will be used instead), and 'key' is

the tag that is to be used as an argument for the `\cite` commands in the text of the article. ‘Bibliography entry’ is the material that is to appear in the list of references, suitably formatted. The commands

```
\usepackage[longnamesfirst,sort]{natbib}
\bibpunct[, ]{({})}{;}{a}{,}{,}
\renewcommand\bibfont{\fontsize{10}{12}\selectfont}
```

need to be included in the preamble of your .tex file in order to generate the citations and bibliography as described above.

Instead of typing the bibliography by hand, you may prefer to create the list of references using a BIB_TE_X database. For this we suggest using Erik Meijer’s `apacite` package, which is available via CTAN if you do not already have it. The `apacite.sty`, `apacite.bst` and (assuming your paper is written in English) `english.apc` files need to be in your working folder or an appropriate directory, the commands

```
\usepackage[natbibapa,nodoi]{apacite}
\setlength\bibhang{12pt}
\renewcommand\bibliographysize{\fontsize{10}{12}\selectfont}
```

included in the preamble of your .tex file instead of the `\usepackage[] {natbib}`, `\bibpunct` and `\renewcommand\bibfont` commands described above, and the lines

```
\bibliographystyle{apacite}
\bibliography{interactapasample}
```

included where the list of references is to appear, where `interactapasample.bib` is the bibliographic database included with the Interact-APA L^AT_EX bundle (to be replaced with the name of your own .bib file). The `[natbibapa]` option has to be added to `\usepackage[] {apacite}` in order to enable citation commands of the type `\citep` and `\citet`. L^AT_EX/BIB_TE_X will extract from your .bib file only those references that are cited in your .tex file and list them in the References section.

Please include a copy of your .bib file and/or the final generated .bbl file among your source files if your .tex file does not contain a reference list in a `thebibliography` environment.

8. Appendices

Any appendices should be placed after the list of references, beginning with the command `\appendix` followed by the command `\section` for each appendix title, e.g.

```
\appendix
\section{This is the title of the first appendix}
\section{This is the title of the second appendix}
```

produces:

Appendix A. This is the title of the first appendix

Appendix B. This is the title of the second appendix

subsections, equations, figures, tables, etc. within appendices will then be automatically numbered as appropriate. some theorem-like environments may need to have their counters reset manually (e.g. if they are not numbered within sections in the main text). You can achieve this by using `\numberwithin{remark}{section}` (for

example) just after the `\appendix` command.

Appendix A. Troubleshooting

Authors may occasionally encounter problems with the preparation of a manuscript using L^AT_EX. The appropriate action to take will depend on the nature of the problem:

- (i) If the problem is with L^AT_EX itself, rather than with the actual macros, please consult an appropriate L^AT_EX 2_ε manual for initial advice. If the solution cannot be found, or if you suspect that the problem does lie with the macros, then please contact Taylor & Francis for assistance (latex.helpdesk@tandf.co.uk).
- (ii) Problems with page make-up (e.g. occasional overlong lines of text; figures or tables appearing out of order): please do not try to fix these using ‘hard’ page make-up commands – the typesetter will deal with such problems. (You may, if you wish, draw attention to particular problems when submitting the final version of your manuscript.)
- (iii) If a required font is not available on your system, allow T_EX to substitute the font and specify which font is required in a covering letter accompanying your files.

Appendix B. Obtaining the template and class file

B.1. *Via the Taylor & Francis website*

This article template and the `interact` class file may be obtained via the ‘Instructions for Authors’ pages of selected Taylor & Francis journals.

Please note that the class file calls up the open-source L^AT_EX packages `booktabs.sty`, `epsfig.sty` and `rotating.sty`, which will, for convenience, unpack with the downloaded template and class file. The template optionally calls for `natbib.sty` and `subfigure.sty`, which are also supplied for convenience.

B.2. *Via e-mail*

This article template, the `interact` class file and the associated open-source L^AT_EX packages are also available via e-mail. Requests should be addressed to latex.helpdesk@tandf.co.uk, clearly stating for which journal you require the template and class file.