R2Labs Package Documentation

Examples Demonstrating Usage of Tools/Environments and Patched Packages Provided

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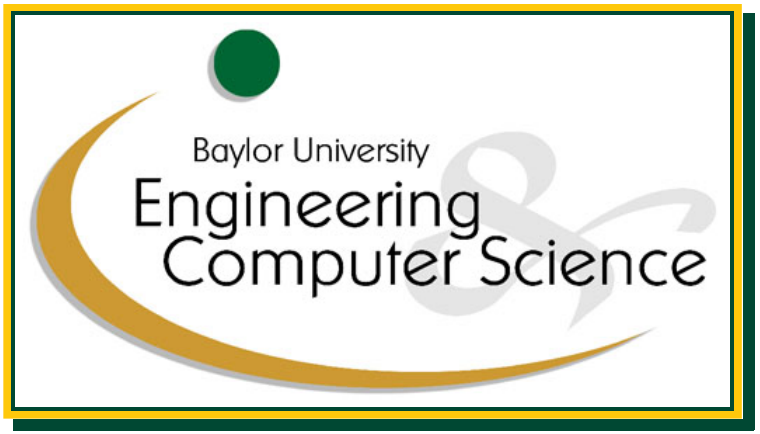

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Part I

General/Universal Content

1 Package Development

1.1 : Package Comments

1.2 : Package Development Testing

1.2.1 Package Options/Configurations

2 Package Info

Loaded Packages : etoolbox,pgffor,ifplatform

Defined Choice Keys : sizeXclo,fontencoding,fontseries,fontshape,frontpagenumbering,docpagenumbering,backpagenumbering,footpagelabeling,fncychap,choiceopttest

1. mylatex@sizeXclo (family@key)
   Acceptable Choices = 10,11,12
   Provided = true
   Selected Choice = 10
2. mylatex@fontencoding (family@key)
   Acceptable Choices = OT1,T1,TS1,OML,OMS,OMX,PD1,PU,U
   Provided = true
   Selected Choice = OT1
3. mylatex@fontseries (family@key)
   Acceptable Choices = l,m,b,bx
   Provided = true
   Selected Choice = m
4. mylatex@fontshape (family@key)
   Acceptable Choices = n,it,sl,sc
   Provided = true
   Selected Choice = n
5. mylatex@frontpagenumbering (family@key)
   Acceptable Choices = arabic,roman,Roman,alph,Alph,fnsymbol
   Provided = true
   Selected Choice = Roman
6. mylatex@docpagenumbering (family@key)
   Acceptable Choices = arabic,roman,Roman,alph,Alph,fnsymbol
   Provided = true
   Selected Choice = arabic
7. mylatex@backpagenumbering (family@key)
   Acceptable Choices = arabic,roman,Roman,alph,Alph,fnsymbol
   Provided = true
   Selected Choice = roman
8. mylatex@footpagelabeling (family@key)
   Acceptable Choices = thepage,oftotal,ofsector,rawpage
   Provided = true
   Selected Choice = thepage
9. mylatex@fncychap (family@key)
   Acceptable Choices = Sonny,Lenny,Glenn,Conny,Rejne,Bjarne,Bjornstrup,PetersLenny

Provided = true
Selected Choice = Sonny

10. mylatex@choiceopttest (family@key)
    Acceptable Choices = choiceone,choicetwo,choicethree
    Provided = true
    Selected Choice = choicetwo

pkgopt queries/printing :

mylatex@fontname=Computer Modern Roman (user defined)
mylatex@fontfamily=cmr (user defined)
mylatex@valid@fontname@choiceval@options= Adobe Courier/pcr, Adobe Helvetica/phv, Adobe New Century Schoolbok/pnc, Adobe Palatino/ppt, Adobe Times Roman/ptr, Avant Garde/pag, Bera Sans/fvs, Bera Serif/fve, Bookman/pbk, Charter/bch, CM Bright/cmbr, CM Roman/cmr, CM Sans/cmss, CM Sans Serif/cmss, CM Typewriter/cmtt, CM Typewriter Light/cmtl, Computer Modern Bright/cmbr, Computer Modern Roman/cmr, Computer Modern Sans/cmss, Computer Modern Sans Serif/cmss, Computer Modern Typewriter/cmtt, Computer Modern Typewriter Light/cmtl, Courier/pcr, Fourier/put, Helvetica/phv, ITC Bookman/pbk, ITC Avant Garde Gothic/pag, Latin Modern Dunhill/lmdh, Latin Modern Roman/lmr, Latin Modern Sans Serif/lmss, Latin Modern Sans Typewriter/lmtt, LM Dunhill/lmdh, LM Roman/lmr, LM Sans Serif/lmss, LM Sans Typewriter/lmtt, New Century Schoolbook/pnc, Palatino/ppl, TEX Gyre Termes/qtm, TEX Gyre Pagella/qpl, TEX Gyre Bonum/qbk, TEX Gyre Schola/qcs, TEX Gyre Adventor/qag, TEX Gyre Heros/qhv, TEX Gyre Cursor/qcr, Times/ptm, URW Classico/uop, Utopia/put, Zapf Chancellery/pzc
@doc@fontsize=10pt
f@halfsize=5.0pt
mylatex@exampleDir=C:/Users/Blake/Documents/GitHub/BlakeSchultze/LaTeX-Packages/doc/Examples/

2.2.1 Argument Parsing/Manipulation

ARGUMENTPARSINGS@TESTING:

split csv arg parsing :

1=>2.5pt
2=>2.5pt
argin=>argout
argmid=>argin
argout=>argin
defmid=>3
argout=>argin
defmid=>iv
@saved@length=>14.0pt

Parsecsvgroups :

Comma-Separated Parentheses/Bracket/Brace Groups :

parsecsvgroups :

(3,0,10)
(3,1)
(2,1)
(2,2)
(2,3)
(1,3)
(1,4)
{3,0}
{3,1}
{2,1,14}
{2,2}
{2,3}
{1,3}
{1,4}
{1,5}
[3,0]
[3,1]
[2,1,13]
[2,2]
[2,3]
[1,3]
[1,4]

parsecsvgroups :

Mixed Parse Group :

parsecsvgroups :

{3,0}
[3,1]
[2,1,14]
(2,2)
{2,3,12}
(1,3,912)

[1,4]
{1,5}
Pair
Pair
Triplet
Pair
Triplet
Triplet
Pair
Pair

xsv group conversions :

comma→braces :

@the@bsv@args:
1=E
2=F
3=G
4=H @the@bsv@args:
1=E
2=F
3=G
4=H @the@bsv@args:
1=E
2=F
3=G
4=H

csvlist: unique add/del :

test,testA,testB

csv(e,g,x)del :

test,testA,testB,

create/add to/appending csvgrouplists :

create@csvgroup :

thecsvgroup=(num1),(num2),(num3),(num4)
csnamecsvgroup=(num1),(num2),(num3),(num4)

add@to@csvgrouplist (create if undef) :

thecsvgrouptest=(num1),(num2),(num3),(num4)

csvgrouplist@distribute@csv (create if undef) :

thecsvgroup=(num1,numa),(num2,numb),(num3,numc),(num4,numd)
thecsvgroup=(num1,numa,numA),(num2,numb,numB),(num3,numc,numC),(num4,numd,numD)

csv@groups@to@grouplist :

thecsvgroup=(num1,numa,numA),(num2,numb,numB),(num3,numc,numC),(num4,numd,numD)

ARGPACK TESTING :

argi=four
argii=five 7seven
argiii=List of Code Listings
lastvarg=

lastvargcmd (argpack u{-} arg) :

1=one
2=two
3=four

getCSVindex :

f
$\{a,b,c,d,e,f,g,h,i,j,k\}_{13\ \mathrm{Mod}(11)=2} = c$
Index 9 = j

b
Index 14 = d

@dup@item@csvlist :

@@filled@csvlist(11)=a,b,c,d,e,f,f,f,f,f,f
@@partial@csvlist(6)=a,b,c,d,e,f
@@filled@csvlist(11)=a,b,c,d,e,f,f,f,f,f,f
@@partial@csvlist(6)=a,b,c,d,e,f
@@filled@csvlist(11)=A,A,A,A,A,A,A,A,A,A,A
@@partial@csvlist(11)=A,A,A,A,A,A,A,A,A,A,A
@@filled@csvlist(11)=A,A,A,A,A,A,A,A,A,A,A
@@partial@csvlist(11)=A,A,A,A,A,A,A,A,A,A,A
@@filled@csvlist(11)=A,A,A,A,A,A,A,A,A,A,A

@@partial@csvlist(1)=A

mod parse brace separated value argument lists :

argi=A,argii=B
argi=C,argii=D
argi=E,argii=F
argi=G,argii=H
argi=A,argii=Bargi=C,argii=Dargi=E,argii=Fargi=G,argii=H

misc arg parsing :

a, b, c, d, e, f, g,
a,b,c,d,e,f, and g
a, b, c, d, e, f, g, h, i, j, k
A, B, C, D, E, F, G, H
A, B, C, D, EE, F, GGG, H, I, JJJ, K, FinalArgument
@TF@indicator@typesB@length=7
7

2.2.2 Lists/Groups

XSV@LISTS@TESTING:

XSV list creation :

figure

csdefnumname/thecsnumname TESTING :

Description: csdefnumname/thecsnumname commands have modifiable prefix (default:'arg'), may include an optional suffix, and Boolean arg specification of name/ordinal/fraction text numname
csnumname1=argone def text
csnumname2=argtwo def text

numname=num@to@ordinal :

define:
arg2(!)=
arg2here(*)=hello 2
arg3=

arg3here=
arg4=
arg4here=
use:
argtwo=hello 1
argtwohere=hello 2
argthree=hello 1
argthreehere=hello 2
argfour=hello 1
argfourhere=hello 2

numname=num@to@ordinal :

define:
thearg2(+)=
thearg2here(+)=
thearg4(!+)=
thearg4here(+)=
use:
theargsecond=hello 1
theargsecondhere=hello 2
theargfourth=hello 1
theargfourthhere=hello 2

num@to@fraction :

define:
thearg12=
thearg32(+)=
thearg12here=
thearg14(!)=
thearg14here=
thearg14here(+)=
thearg34here=
use:
theargonehalf=hello 12
theargthreehalves=hello 32
theargonehalfhere=hello 12
theargonequarter=hello 14
theargonequarterhere=hello 14
theargthreequartershere=hello 34

xsvargdef/thexsvarg :

csvargdef test
csvargdef test

thenumname=one

XSV list usage :

/ion/pCT_code/git/<*GitHub account*>/<*GitHub repository*>
/ion/pCT_code/git/<*GitHub account*>/<*GitHub repository*>/...

2.2.3 Conditional Tests/Statements

CONDITIONALS@TESTING:

cssetTF :

@equality@status@true/false (w/o explicit TF value) :

TFtest(F) =F
@macro@if(F) =F
@macro@toggle(F) =F
binarytest(F) =0
@macro@counter(F) =0

EXPLICIT SET :

@macro@toggle(T) =0
@macro@if(T) =0
TFtest(T) =T
TrueFalsetest(T) =T
@macro@if(T) =T
@macro@toggle(F) =F

DEFAULT SET :

@macro@counter(F) =0
xparsetest(F) =Γ

@print@conditional :

@macro@toggle=F
@macro@toggle=
@macro@if=1

@macro@counter=0
TFtest=F

csregsetTF TESTING :

F (F)
T (T)
F (F)
T (T) no numcomp
not defined

TFcomparisons :

TFcompare(F) =F
TFcompare(T) =T
TFcompare(T) =
TFcompare(T) =T

ifTFdo :

F (F)
T (F)
T (T)
T (T)

if@X :

Individual Conditionals :

ifismacro{bshift}=macro
ifismacro{thebshift}=not macro

Composite Conditionals :

ifAnd:=F (F)
ifXOr:=F (T)
ifOr:=F(F)

negated@if@X@TESTING :

ifdefempty :

empty:T
empty(negated):F

nonempty:F
nonempty(negated):T

ifdefunequal :

equal:F
equal(negated):F
unequal:T
unequal(negated):T

If(X)EqCase :

IfCSEqCase :

`hello`
Hello *there*

IfDefEqCase :

`hello`
Hello *there*

do@once :

2.2.4 Register/Variable Interaction

REGVAR@TESTING:

theX@regprint :

bigskipamount=12.0pt plus 4.0pt minus 4.0pt
the@macro@length=2.5pt
the@macro@toggle=T
the@measure@cfootpos=T
the@measure@pos=T
thebshift=0.15pt
the@macro@skip=0.0pt
T
T
F

F
F
F

@set@varname@reg :

26.35pt
5.0pt
5.0pt
5.0pt
5.0pt

@zsavepos@TESTING :

bottom@coverpage=18.06749pt
cfootpos=0.0pt
bottom@page=36.135pt
bottom@coverpage=18.06749pt
top@docpage=570.93257pt
cfootpos=0.0pt

fractional space dimension settings :

abc abc -abc abc -
1.66559pt
1.6663pt
3.33333pt
3.33333pt
3.33333ptplus 1.66666ptminus 1.11111pt
3.33333pt plus 1.66666pt minus 1.11111pt
3.33333pt plus 1.66666pt minus 1.11111pt
3.33333pt plus 1.66666pt minus 1.11111pt

onequarter@spacing=0.83333pt
onehalf@spacing=1.66666pt
threequarters@spacing=2.49998pt
threehalves@spacing=4.99998pt
onethird@spacing=1.11108pt
twothirds@spacing=2.22218pt
fourthirds@spacing=4.44441pt
sevenquarters@spacing=5.83331pt

Text dimension measurements :

measure=letters,maxheight=true:@measure@text 2/3=4.30554pt
measure=letters,maxheight=true,format=, saveas=testsaveas:@measure@text testsaveas 2/3=6.8889pt

measure=letters,maxheight=true,format=,arg=x:@measure@text 2/3=3.87498pt
measure=letters,maxheight=true,format=tiny:@measure@text 2/3=3.22221pt
measure=letters,arg=X,format=tiny:@measure@text 2/3=3.3988pt
measure=numbers,format=LARGE:@measure@text 2/3=10.31111pt
3:@measure@text 3=3.87498pt
none:@measure@text none=3.87498pt

@init@X :

op(count)→print(count) :

0
1
4
12
13
12

setcountval :

“ONE:defcounter=bsvargi
ONE:cscounter=bsvargi
@macro@counter:ltxcounter=bsvargii
c@@macro@counter:cscounter=bsvargii
“c@@macro@counter:defcounter=bsvargii
3:integer=bsvargiii

2.2.5 Text/Paragraphs

TEXTPAR@TESTING:

numToText :

one
testargonedef

Ordinals :

zeroth

fourth
tenth
fourteenth
fortieth
fortieth
onehundredth
twohundredth
onethousandth
onehundredtwentyfourthousandfivehundredsixtyseventh
onemilliontwohundredthirtyfourthousandfivehundredsixtyseventh
onebillionth
onebillionth
onebillionfivehundredeightysevenmilliononehundredthirtyfourthousandsevenhundredtwentyninth
onebillionfivehundredeightysevenmilliononehundredthirtyfourthousandsevenhundredtwentyninth

Fractions :

onehalf
onehalf
onehalf
onehalf
threehalves
threehalves
threehalves
three@halves
onethird
onequarter
onequarter
three@quarters
one@fourteenth
twoonehundredfourths

twoonehundredseconds
twoonehundredtwentieths
twoonehundredtwentieths
twoonehundredfortieths
twoonehundredfortieths
fourfortieths
fourfortieths

Names :

zero

one hundred
one thousand
ten thousand
one hundred thousand
one million
ten million
one hundred thousand, seven hundred twenty–nine
one hundred thousand, seven hundred twenty–nine
onehundredthousandsevenhundredtwentynine
one million, seven hundred nineteen
one million, seven hundred nineteen
onemillionsevenhundrednineteen
elevenmillion, onehundredtwentyseventhousand
fivehundredeightysevenmillion, sevenhundredtwentynine
one billion
one billion
one billion, five hundred eighty–seven million, one hundred thirty–four thousand, seven hundred twenty–nine
one billion, five hundred eighty–seven million, one hundred thirty–four thousand, seven hundred twenty–nine

Counter Ordinals :

zero
four
figure

ul@TESTING :

varuline:Blupp of (that's *of*, not *off*, of course) a great Synopsis
varul:Blupp of (that's *of*, not *off*, of course) a great Synopsis
underline:Blupp of (that's *of*, not *off*, of course) a great Synopsis
tikzUL:Blupp of (that's *of*, not *off*, of course) a great Synopsis
ul:Blupp of (that's *of*, not *off*, of course) a great Synopsis
uline:Blupp of (that's *of*, not *off*, of course) a great Synopsis

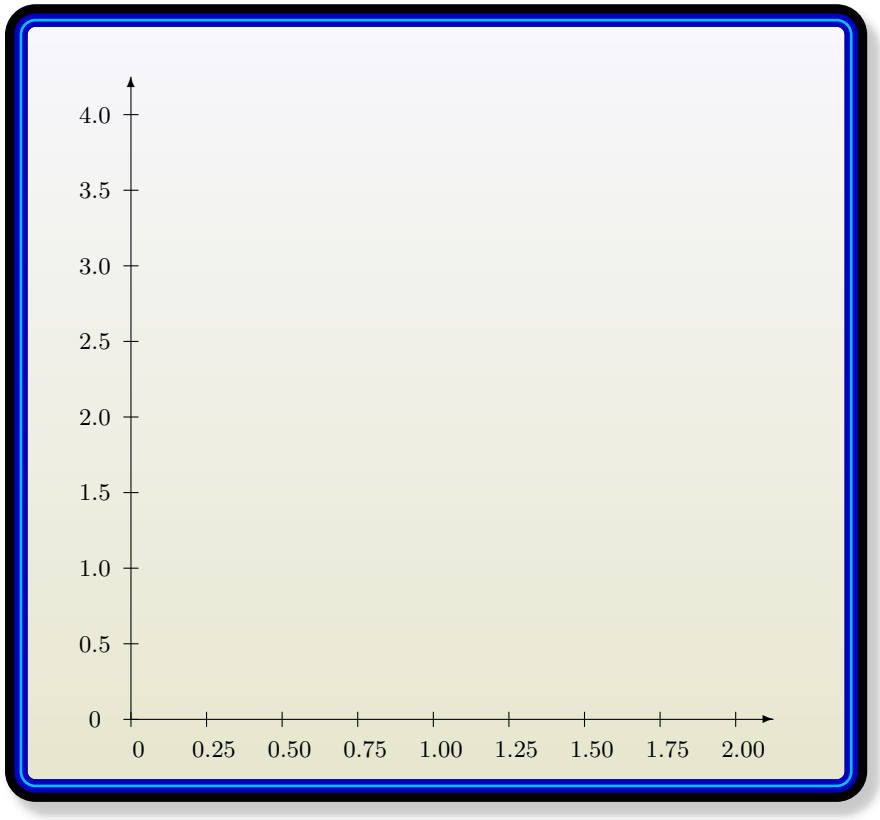
2.2.6 Math/Equations

Some arithmetic: $27 + 10 = 37$ -9.0 d

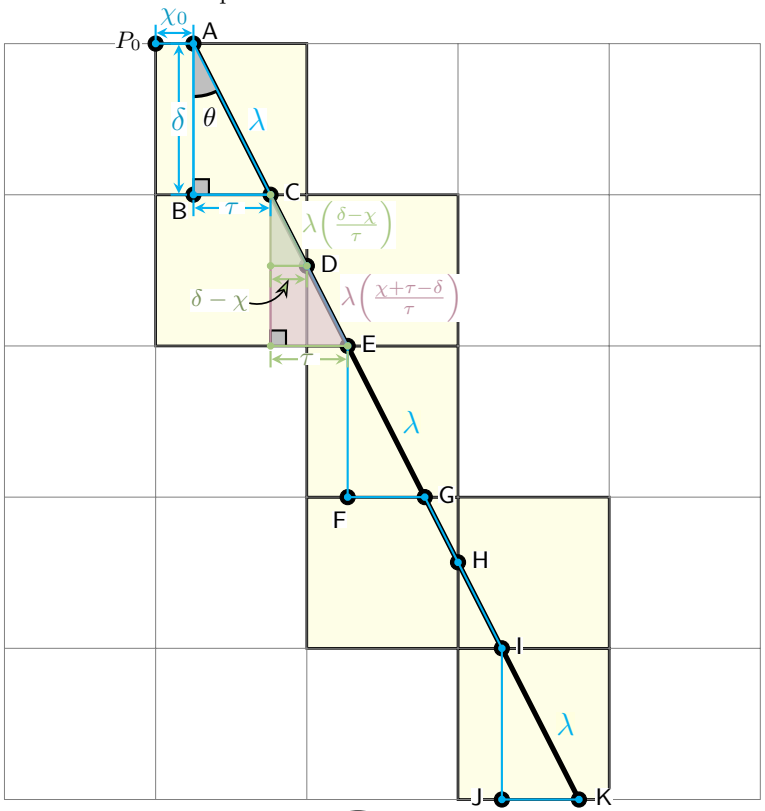
2.2.7 Macro Testing

2.2.8 Graphics/Image Testing

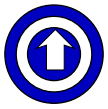
hello1
hello2
tablehello3

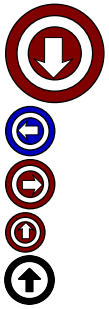


line before DDA plot



line following DDA plot





Standard 2D Digital Difference Analyzer (DDA)

procedure DDA($\mathcal{I}, \delta, \theta, x_0$)
  $\tau = \delta \tan(\theta)$
  $\lambda = \delta / \tan(\theta)$
  $\chi_0 = x_0 - x(A)$
  $P_0 = p(x_0, y_0)$ ▷ p coordinates $(x, y) \rightarrow$ pixel P
  while $\big(x(P_n), y(P_n)\big) \in \mathcal{I}$ **do**
    if $\chi_n + \tau < \delta$ **then**
      $l(P_n) = \lambda$
      $\chi_{n+1} = \chi_n + \tau$
      $P_{x,n+1} = P_{x,n}$
      $P_{y,n+1} = P_{y,n} + 1$
    else
      $l(P_n) = \lambda\left(\frac{\delta - \chi_n}{\tau}\right)$
      $P_{x,n+1} = P_{x,n} + 1$
      $P_{y,n+1} = P_{y,n}$
      $n = n + 1$
      $P_n = p(P_{x,n}, P_{y,n})$
      if $P_n \in \mathcal{I}$ **then**
        $l(P_n) = \lambda\left(\frac{\chi_n + \tau - \delta}{\tau}\right)$
        $\chi_{n+1} = \chi_n + \tau - \delta$
        $P_{x,n+1} = P_{x,n}$
        $P_{y,n+1} = P_{y,n} + 1$
      end if
    end if
    $x_{n+1} = x_n + \tau$
    $y_{n+1} = y_n + \delta$
    $n = n + 1$
    $P_n = p(P_{x,n}, P_{y,n})$
  end while
end procedure

2.2.9 Color/Style Testing

COLOR@TESTING:

50
75
25
25

Custom color mix/set definitions :

@defined@colormixes=stdgray,stddkgray,stdltgray,stdLTgray,stdbackground,stddkbackground,stdDKbackground,stdltbackground,stdblue,stddkblue,stdDKblue,stdltb
tint,stddkgreen-lowtint,stddkgreen-medtint,stddkblue-tint,stddkblue-lowtint,stddkblue-hightint,stddkblue-medtint,stddkred-tint,stddkred-lowtint,TintedSlateGray,dia
background,inlineboxgray,inlineboxblue,inlineboxltblue,hyperlinkcolor,Matlab-autohighlight-shade,listboxgray
@defined@colorsets=default,current,fillednumshape,bash-extended,git,matlab-extended,majorSectionHeading,diagram,documentation
@defined@tcbcolorsets=definition,IBP,LD,Matlab,PLD,problem,solution,tcbbashbox,tcbdiagram,tcbenvironment,tcbequation,tcbeqnlistbox,tcbfigbox,tcbfigure,tcbfun

2.2.10 Misc: Links/Bookmarks

2.2.11 Misc./Temporary Testing

Misc. Temporary Testing:

I

3.1 : Misc. Examples

First line section content

3.1.1 Misc: Register Variables

3.1
0
0
0.0
0
0
3.1
0
0
0.0
0
4
0
1
T
T
F
F
F
F
abcd- -F- –abcd
abcd- -T- –abcd

3.1.2 Misc: Links/Bookmarks

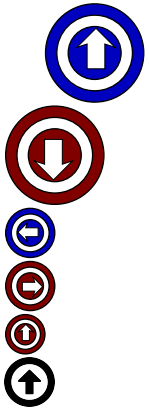
3.1.3 Misc: Text/Paragraphs

“errmessage“protected macro:-¿ “loadgeometry –doc@geometry″“zsavepos –top@docpage″“setlength “@cfoot@yshift –“paperheight - (1in + “voffset + “topmargin + “headheight + “headsep + “textheight) - “footskip ″ “pagestyle –fancy″“pagenumbering –“mylatex@docpagenumbering ″“setcounter –page″–1″“doclinespacing “toggletrue –@add@PAGE@targets″
myulB:
Blupp of (that's *of*, not *off*, of course) a great Synopsis
varul:
jumping quickly
jumping quickly
jumping quickly
jumping quickly
jumping quickly
jumping quickly
uline=sdsdsd
varul:
jumping quickly
jumping quickly
jumping quickly
jumping quickly
jumping quickly
jumping quickly
underline
tikzUL
ul
uline=uline
varul:
jumping quickly
jumping quickly
myulB:

3.1.4 Misc: Math/Equations

Some arithmetic: $27 + 10 = 37$ -9.0 d

3.1.5 Misc: Images/Graphics



Part II

Document Section Examples

4 Example Chapter* + Section

4.1 : Example Chapter*: Section

First line Subsection4.1content

5 Example Chapter* + Subsection

5.1.1 Example Chapter*: Subsection

First line Subsection5.1.1content

5.1.2 organized_data Hierarchy

6 Example Chapter* + Text + Section

First line Subsection6.1content

6.1 : Example Chapter*: Text + Section

7 Example Chapter* + Section + Text

7.1 : Example Chapter*: Section + Text

First line Subsection7.1content

8 Example Chapter + Section + Text

8.1 : Example Chapter: Section + Text

First line Subsection8.1content

9 Example Chapter + Text + Section

First line Subsection9.1content

9.1 : Example Chapter: + Text + Section

bottom@coverpage=18.06749pt
cfootpos=0.0pt

9.2 : Front/back Matter Examples

and then and then and then and then and then and then and then and then and then
real number,π,Linux,Logical Volume Manager (LVM),Frame per Seconds (FPSs),Frame per Second (FPS)
m,$\widetilde{m}$,$f(\cdot)$,Ω
Collaborative Faculty Research Investment Program (CFRIP),One-Way Delay (OWD),OWD,OWD,OWD,OWD's,OWD's,OWDs
MFA etc

Part III

Custom Package Environments

10 Float/Graphics Examples

10.1 : Figure Examples

Figure Box 1

Figure 1: Plots $ax = b$ of $ax = b$ the the the Dolph-Chebyshev windo $ax = b$ for $ax = b$ ad $ax = b$ fsfsf sfsfsfsf fsfs sfsf add

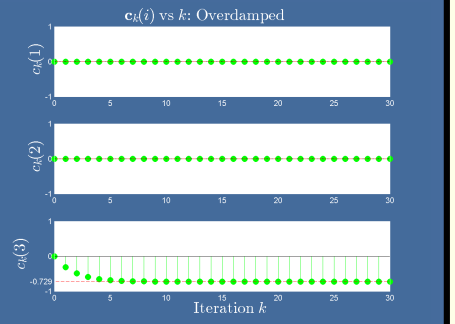


Figure 2: Plots of Dolph-Chebyshev window for

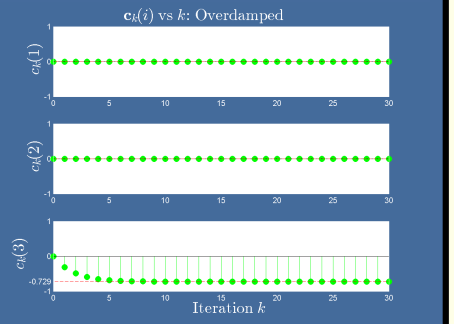


Figure 3: hellob3

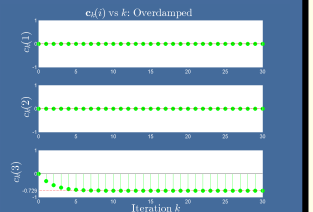


Figure 4: hellob2

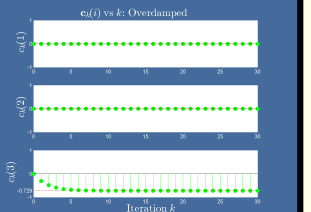


Figure 5: hellob

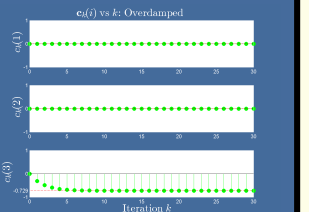


Figure Box 2 : hello title

Figure 6: Plots of Dolph-Chebyshev windo for ad fsfsf sfsfsfsf $ax = b$ fsfs sfsf add

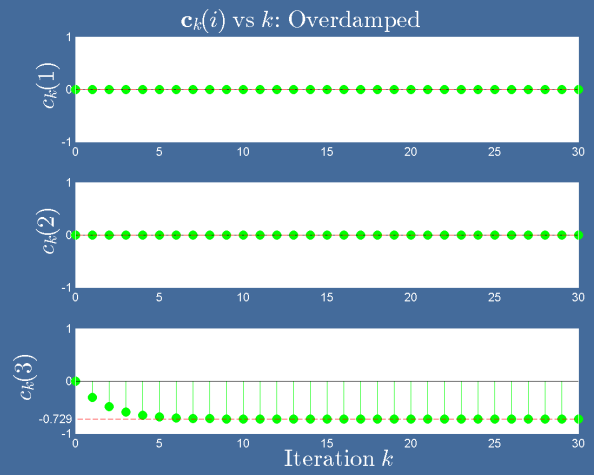


Figure 7: Plots of Dolph-Chebyshev window for

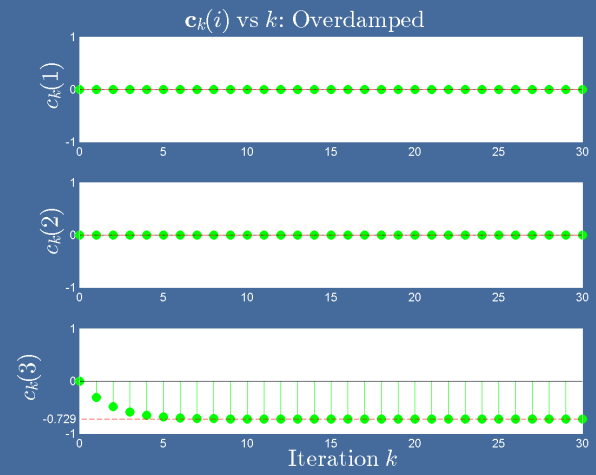


Figure 8

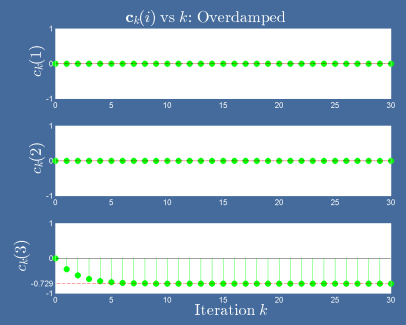


Figure 9: hellob2

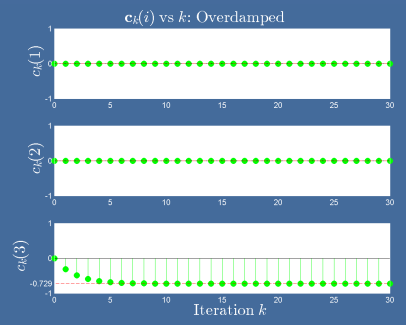
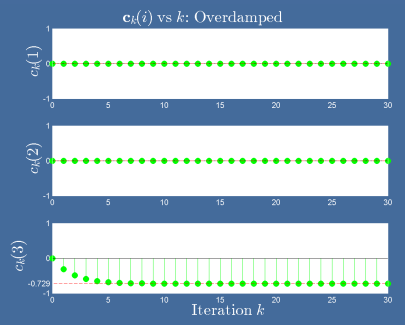


Figure 10: hellob



10.2 : Math Table Examples

10.2.1 Long Division Tables

$$5\overline{)\,12345}$$

$$\begin{array}{r} 2469 \\ 5\overline{)\,12345} \end{array}$$

$$\begin{array}{r} 2469 \\ 5\overline{)\,12345} \\ -10000 \\ \hline 2345 \\ -2000 \\ \hline 345 \\ -300 \\ \hline 45 \\ -45 \\ \hline 0 \end{array}$$

LD Table 1: $5\overline{)12345}$

$$
\begin{array}{r}
2469 \\
5\overline{)12345} \\
-10000 \\
\hline
2345 \\
-2000 \\
\hline
345 \\
-300 \\
\hline
45 \\
-45 \\
\hline
0
\end{array}
$$

10.2.2 Integration by Parts Tables

IBP Table 1: $\int x^2\, e^{-x}\, dx$

u		dv
x^2	$+$	e^{-x}
$2x$	$-$	$-e^{-x}$
2	$+$	e^{-x}

TITLESF TEXT HERE

IBP Table 2

u	dv
x	e^{-x}
1	$-e^{-x}$

IBP Table 3: text description

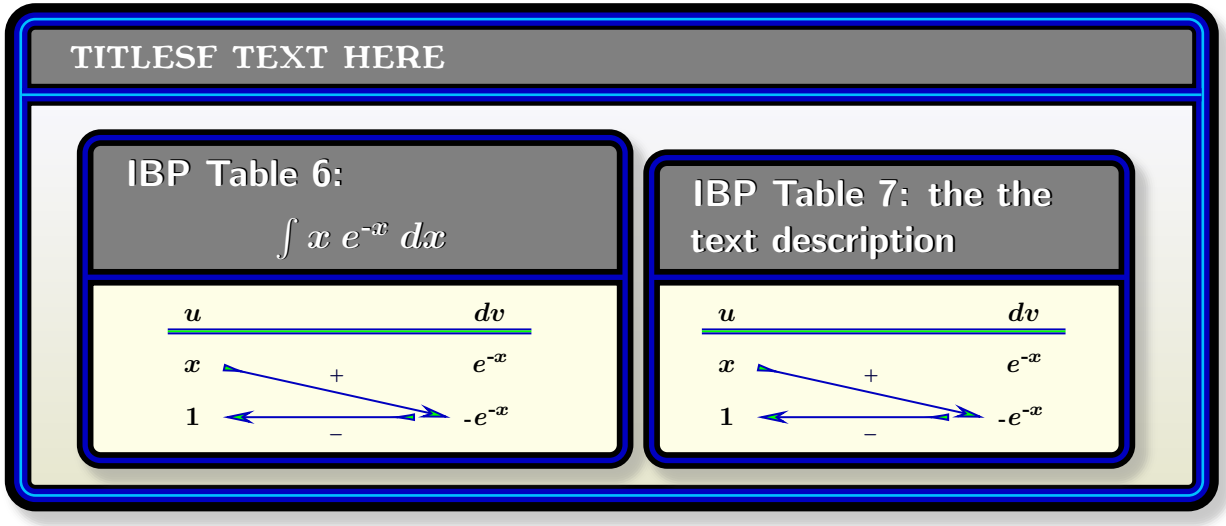
u	dv
x	e^{-x}
1	$-e^{-x}$

IBP Table 4: $\int x\, e^{-x}\, dx$

u	dv
x	e^{-x}
1	$-e^{-x}$

IBP Table 5: the the text description

u	dv
x	e^{-x}
1	$-e^{-x}$



10.2.3 Polynomial Long Division Examples

PLD Table 1:

$$f(x) = \frac{x^4 + 0x^3 + 2x^2 + 2x + 1}{x^2 + 1}$$

$$\begin{array}{r} x^2 \qquad\quad + 1 + \frac{2x}{x^2+1} \\ x^2+1 \,\overline{)\; x^4 + 2x^2 + 2x + 1} \\ \underline{-\,x^4 \;\; -\,x^2} \\ x^2 + 2x + 1 \\ \underline{-\,x^2 \qquad -\,1} \\ 2x \end{array}$$

PLD Result :

$$\Longrightarrow \quad \frac{x^4 + 2x^2 + 2x + 1}{x^2 + 1} = x^2 + 1 + \frac{2x}{x^2 + 1}$$

PLD Table 2:

$$\begin{array}{r|l} x^2+1 & x^4+2x^2+2x+1 \\ & \underline{-x^4-x^2} \\ & \quad x^2+2x+1 \\ & \quad \underline{-x^2\quad -1} \\ & \qquad 2x \end{array} \qquad x^2+1+\frac{2x}{x^2+1}$$

PLD Result :

$$\Rightarrow \frac{x^4+2x^2+2x+1}{x^2+1} = x^2+1+\frac{2x}{x^2+1}$$

PLD Table 3:

$$f(x) = \frac{x^4+0x^3+2x^2+2x+1}{x^2+1}$$

$$\begin{array}{r|l} x^2+1 & x^4+2x^2+2x+1 \\ & \underline{-x^4-x^2} \\ & \quad x^2+2x+1 \\ & \quad \underline{-x^2\quad -1} \\ & \qquad 2x \end{array} \qquad x^2+1+\frac{2x}{x^2+1}$$

PLD Result :

$$\Rightarrow \frac{x^4+2x^2+2x+1}{x^2+1} = x^2+1+\frac{2x}{x^2+1}$$

PLD Table 4: hello

$$
\begin{array}{r}
x-1 \\
x-1\,\overline{)\;x^2-2x+1} \\
\underline{-x^2+x} \\
-x+1 \\
\underline{x-1} \\
0
\end{array}
$$

$$
\begin{array}{r}
x-1 \\
x-1\,\overline{)\;x^2-2x+1} \\
\underline{-x^2+x} \\
-x+1 \\
\underline{x-1} \\
0
\end{array}
$$

11 Problem Examples

(3.8) For each of the following, determine whether the random process is (1) WSS or (2) m.s. ergodic in the mean.

PROOF:

Beginning with the check of WSS

$$\mu_x = \mathbb{E}\big[x(n)\big] = \mathbb{E}\big[A(\zeta)\big] = \frac{1}{2} \quad : \text{constant} \tag{3.8-1}$$

$$r_x(n_1, n_2) = \mathbb{E}\big[x(n_1,\zeta)x(n_2,\zeta)\big] = \mathbb{E}\Big[A^2(\zeta)\Big] = \int_0^1 x^2\,dx = \frac{x^3}{3}\Big|_{x=0}^{1} = \frac{1}{3} \quad : \text{constant} \tag{3.8-2}$$

$$r_x(n_1, n_2) = \begin{cases} \mathbb{E}\big[x(n_1)x^*(n_2)\big] = \mathbb{E}\big[x(n_1)\big]\mathbb{E}\big[x(n_2)\big] = (2p-1)(2p-1) = (2p-1)^2 & \text{if } \boldsymbol{n_1 \neq n_2} \\ \mathbb{E}\big[x(n)x^*(n)\big] = \sum x(n)x^*(n)\Pr{*X_n = x} = (1)^2\cdot p + (-1)^2\cdot(1-p) = p + (1-p) = 1 & \text{if } \boldsymbol{n_1 = n_2 = n} \end{cases} \tag{3.8-3}$$

However, notice that the random variable $x(n,\zeta) = A(\zeta)$ is constant for a particular value of ζ and although its expected value is consistent with the mean of the process, the sequence $x(n,\zeta)$ remains constant as $N \to \infty$ and therefore, the sample mean does not converge to the population mean μ_x.

Therefore, since $\mathbb{E}\Big[\langle \boldsymbol{x(n)} \rangle\Big]$ does not converge to the population mean $\boldsymbol{\mu_x}$ and, hence, the process is not M.S. ergodic in the mean.

Continuing with a check of whether the random variable is M.S. ergodic in the mean:

$$\mathbb{E}\Big[\langle x(n)\rangle\Big] = \mathbb{E}\left[\frac{1}{2N+1}\sum_{-N}^{N} x(n)\right] = \frac{1}{2N+1}\sum_{-N}^{N}\mathbb{E}\big[x(n)\big] = \frac{1}{2N+1}\sum_{-N}^{N}\mathbb{E}\big[A(\zeta)\big] = \frac{1}{2} \tag{3.8-4}$$

$$\mathbb{E}\Big[\langle x(n)\rangle\Big] = \mu_x \quad \checkmark \tag{3.8-5}$$

WSS Results

1. $\boldsymbol{\mu_x = \frac{1}{2}}$: **constant**
2. $\boldsymbol{r_x(n_1, n_2) = \frac{1}{3}}$: **constant**
3. $\Longrightarrow$ $\boldsymbol{X(t) = A(\zeta)}$ **is WSS**

(4.2) For each of the following, determine whether the random process is (1) WSS or (2) m.s. ergodic in the mean.

Solution:

Beginning with the check of WSS

$$\mu_x = \mathbb{E}\big[x(n)\big] = \mathbb{E}\big[A(\zeta)\big] = \frac{1}{2} \quad : \text{constant} \tag{4.2-1}$$

$$r_x(n_1, n_2) = \mathbb{E}\big[x(n_1,\zeta)x(n_2,\zeta)\big] = \mathbb{E}\Big[A^2(\zeta)\Big] = \int_0^1 x^2\,dx = \frac{x^3}{3}\Big|_{x=0}^{1} = \frac{1}{3} \quad : \text{constant} \tag{4.2-2}$$

$$\boldsymbol{\mu_x = \mathbb{E}\Big[A^2(\zeta)\Big]} \tag{4.2-3}$$

$$\boldsymbol{\mu_x = \mathbb{E}\Big[A^2(\zeta)\Big]} \tag{4.2-4}$$

$$\boldsymbol{\mu_x = \mathbb{E}\Big[A^2(\zeta)\Big]} \tag{4.2-5}$$

$$\boldsymbol{\mu_x = \mathbb{E}\Big[A^2(\zeta)\Big]}$$

$$r_x(n_1, n_2) = \begin{cases} \mathbb{E}\big[x(n_1)x^*(n_2)\big] = \mathbb{E}\big[x(n_1)\big]\mathbb{E}\big[x(n_2)\big] = (2p-1)(2p-1) = (2p-1)^2 & \text{if } \boldsymbol{n_1 \neq n_2} \\ \mathbb{E}\big[x(n)x^*(n)\big] = \sum x(n)x^*(n)\Pr{*X_n = x} = (1)^2\cdot p + (-1)^2\cdot(1-p) = p + (1-p) = 1 & \text{if } \boldsymbol{n_1 = n_2 = n} \end{cases} \tag{4.2-6}$$

However, notice that the random variable $x(n,\zeta) = A(\zeta)$ is constant for a particular value of ζ and although its expected value is consistent with the mean of the process, the sequence $x(n,\zeta)$ remains constant as $N \to \infty$ and therefore, the sample mean does not converge to the population mean μ_x.

Therefore, since $\mathbb{E}\Big[\langle \boldsymbol{x(n)} \rangle\Big]$ does not converge to the population mean $\boldsymbol{\mu_x}$ and, hence, the process is not M.S. ergodic in the mean.

Continuing with a check of whether the random variable is M.S. ergodic in the mean:

$$\mathbb{E}\Big[\langle x(n)\rangle\Big] = \mathbb{E}\left[\frac{1}{2N+1}\sum_{-N}^{N} x(n)\right] = \frac{1}{2N+1}\sum_{-N}^{N}\mathbb{E}\big[x(n)\big] = \frac{1}{2N+1}\sum_{-N}^{N}\mathbb{E}\big[A(\zeta)\big] = \frac{1}{2} \tag{4.2-7}$$

$$\mathbb{E}\Big[\langle x(n)\rangle\Big] = \mu_x \quad \checkmark \tag{4.2-8}$$

1. Mean $= \boldsymbol{\mu_x = 1 > 0} \implies \boldsymbol{f_x(x)}$ is shifted to the right of the origin
2. Variance $= \mathbf{var}\{\boldsymbol{x(\zeta)}\} \triangleq \boldsymbol{\sigma_x^2 = 1 > 0} \implies \boldsymbol{f_x(x)}$ has an equal spread in values as a standard Gaussian
3. Skewness $\triangleq \boldsymbol{\tilde{\kappa}_x^{(3)} = 2 > 0} \implies \boldsymbol{f_x(x)}$ leans right.
4. Kurtosis $= \boldsymbol{\tilde{\kappa}_x^{(4)} = 6 > 0} \implies \boldsymbol{f_x(x)}$ has a much sharper peak than a standard Gaussian

1. $\boldsymbol{\mu_x = \frac{1}{2}}$: **constant**
2. $\boldsymbol{r_x(n_1, n_2) = \frac{1}{3}}$: **constant**
3. $\implies \boldsymbol{X(t) = A(\zeta)}$ **is WSS**

Solution

1. $\boldsymbol{\mu_x = \frac{1}{2}}$: **constant**
2. $\boldsymbol{r_x(n_1, n_2) = \frac{1}{3}}$: **constant**
3. $\implies \boldsymbol{X(t) = A(\zeta)}$ **is WSS**

(5) For each of the following, determine whether the random process is (1) WSS or (2) m.s. ergodic in the mean.

(6) For each of the following, determine whether the random process is (1) WSS or (2) m.s. ergodic in the mean.

(a) For each of the following, determine whether the random process is (1) WSS or (2) m.s. ergodic in the mean.

(i) For each of the following, determine whether the random process is (1) WSS or (2) m.s. ergodic in the mean.

(3.12) For each of the following, determine whether the random process is (1) WSS or (2) m.s. ergodic in the mean.

(a) For each of the following, determine whether the random process is (1) WSS or (2) m.s. ergodic in the mean.

(3.10) For each of the following, determine whether the random process is (1) WSS or (2) m.s. ergodic in the mean.

(i) For each of the following, determine whether the random process is (1) WSS or (2) m.s. ergodic in the mean.

(a) For each of the following, determine whether the random process is (1) WSS or (2) m.s. ergodic in the mean.

(b) For each of the following, determine whether the random process is (1) WSS or (2) m.s. ergodic in the mean.

12 Math Examples

Xmatrix (outside align) :

$$\begin{bmatrix} AAA & AAA & AAA \\ B & B & B \\ C & C & C \end{bmatrix} \left(\begin{matrix} AAA & AAA & AAA \\ B & B & B \\ C & C & C \end{matrix} \right) \begin{bmatrix} AAA & AAA & AAA \\ B & B & B \\ C & C & C \end{bmatrix} \begin{bmatrix} AAA & AAA & AAA \\ B & B & B \\ C & C & C \end{bmatrix} \begin{bmatrix} AAA & AAA & AAA \\ B & B & B \\ C & C & C \end{bmatrix}$$

Xmatrix (inside align) :

$$\begin{bmatrix} AAA & AAA & AAA \\ B & B & B \\ C & C & C \end{bmatrix} \begin{bmatrix} Agra & Agra & Agra \\ B & B & B \\ C & C & C \end{bmatrix} \begin{bmatrix} An & An & An \\ Bn & Bn & Bn \\ Cn & Cn & Cn \end{bmatrix}$$

$$\det(A) = \begin{matrix} *) \\ -1) \\ -2) \\ -2) \end{matrix} \begin{vmatrix} 1 & 3 & 2 & -6 \\ 1 & 2 & -2 & -5 \\ 2 & 4 & -2 & -9 \\ 2 & 4 & -6 & -9 \end{vmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} Agra & Agra & Agra \\ B & B & B \\ C & C & C \end{bmatrix}$$

Math Mode Line Spacing: 3.0pt

$\mathcal{F}(x)$

$\mathrm{III}_I(x)$

$\log_2(x)$

$\log_2(x)$

$\log_{10}(x)$

$\log_{10}(x)$

$\log_e(x)$

$\operatorname{erf}_2^4(x)$

$\mathbb{P}$

$\lim P$

$\lim_{x \in X}(P)$

$\prod_{x \in X} A_x$

The formula is

$$\begin{aligned} a &= b + c \\ &= 1 + 1 \\ &= 2 \end{aligned}$$

$$\amalg, \angle, \measuredangle, \lhd, \approx, \cong, \approxeq, *, \asymp, \setminus, \because, \between, \bot, \boxminus \tag{3.10-1}$$

$$\boxplus, \boxtimes, \boxdot, \bowtie, \bullet, \cap, \cup, \Cap, \Cup, \cdot, \circledast, \circledcirc, \tag{3.10-2}$$

$$\clubsuit, \curlyvee, \curlywedge, \diamondsuit, \divideontimes, \dotplus, \heartsuit, \spadesuit, \circ, \bigcirc, \cong, \ncong, \dagger, \ddagger, \dashv, \tag{3.10-3}$$

$$\Vdash, \models, \nVdash, \nvDash, \vdash, \nvdash, \Vvdash, \Diamond, \diamond, \boldsymbol{\nabla}\cdot, \equiv, =\!\!=, \neq (=\!\!\neq), \fallingdotseq, \tag{3.10-4}$$

$$\doteq, \doteqdot, \Doteq, \div, \fallingdotseq, \risingdotseq, \exists, \nexists, \flat, \forall, \frown, \smile, , \not>, \gg, \ggg, \geq (=\geq) \tag{3.10-5}$$

$$\ngeq, \geqq, \ngeqq, \geqslant, \ngeqslant, \gtrless, \gtrsim, \gtrsim, \gtrapprox, \gtrsim, \gtrapprox, \gtrsim, \gtrdot, \gtreqless, \gtreqless, \gtrless \tag{3.10-6}$$

$$\gneqq, \in, \notin, \ni, , \intercal, , \lhd, \trianglelefteq, \nwarrow, \nless, , \not<, \ll, \lll, \leq (=\leq), \nleq, \leqq, \tag{3.10-7}$$

$$\tag{3.10-8}$$

13 List and Equation List Box Examples

1. Mean $= \boldsymbol{\mu_x = 1 > 0} \implies \boldsymbol{f_x(x)}$ is shifted to the right of the origin
2. Variance $= \mathbf{var}\{\boldsymbol{x(\zeta)}\} \triangleq \boldsymbol{\sigma_x^2 = 1 > 0} \implies \boldsymbol{f_x(x)}$ has an equal spread in values as a standard Gaussian
3. Skewness $\triangleq \boldsymbol{\tilde{\kappa}_x^{(3)} = 2 > 0} \implies \boldsymbol{f_x(x)}$ leans right.
4. Kurtosis $= \boldsymbol{\tilde{\kappa}_x^{(4)} = 6 > 0} \implies \boldsymbol{f_x(x)}$ has a much sharper peak than a standard Gaussian

1. $\boldsymbol{\mu_x = \frac{1}{2}}$: **constant**
2. $\boldsymbol{r_x(n_1, n_2) = \frac{1}{3}}$: **constant**
3. $\implies \boldsymbol{X(t) = A(\zeta)}$ **is WSS**

Solution

1. $\boldsymbol{\mu_x = \frac{1}{2}}$: **constant**
2. $\boldsymbol{r_x(n_1, n_2) = \frac{1}{3}}$: **constant**
3. $\implies \boldsymbol{X(t) = A(\zeta)}$ **is WSS**

(3.8) For each of the following, determine whether the random process is (1) WSS or (2) m.s. ergodic in the mean.

1. Mean $= \boldsymbol{\mu_x = 1 > 0} \implies \boldsymbol{f_x(x)}$ is shifted to the right of the origin
2. Variance $= \mathbf{var}\{\boldsymbol{x(\zeta)}\} \triangleq \boldsymbol{\sigma_x^2 = 1 > 0} \implies \boldsymbol{f_x(x)}$ has an equal spread in values as a standard Gaussian
3. Skewness $\triangleq \boldsymbol{\tilde{\kappa}_x^{(3)} = 2 > 0} \implies \boldsymbol{f_x(x)}$ leans right.
4. Kurtosis $= \boldsymbol{\tilde{\kappa}_x^{(4)} = 6 > 0} \implies \boldsymbol{f_x(x)}$ has a much sharper peak than a standard Gaussian

1. $\boldsymbol{\mu_x = \frac{1}{2}}$: **constant**
2. $\boldsymbol{r_x(n_1, n_2) = \frac{1}{3}}$: **constant**
3. $\implies \boldsymbol{X(t) = A(\zeta)}$ **is WSS**

Solution

1. $\boldsymbol{\mu_x = \frac{1}{2}}$: **constant**
2. $\boldsymbol{r_x(n_1, n_2) = \frac{1}{3}}$: **constant**
3. $\implies \boldsymbol{X(t) = A(\zeta)}$ **is WSS**

1. Mean $= \boldsymbol{\mu_x = 1 > 0} \implies \boldsymbol{f_x(x)}$ is shifted to the right of the origin
2. Variance $= \mathbf{var}\{\boldsymbol{x(\zeta)}\} \triangleq \boldsymbol{\sigma_x^2 = 1 > 0} \implies \boldsymbol{f_x(x)}$ has an equal spread in values as a standard Gaussian
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4. Kurtosis $= \boldsymbol{\tilde{\kappa}_x^{(4)} = 6 > 0} \implies \boldsymbol{f_x(x)}$ has a much sharper peak than a standard Gaussian

1. $\mu_x = \frac{1}{2}$: constant
2. $r_x(n_1, n_2) = \frac{1}{3}$: constant
3. $\Longrightarrow$ $X(t) = A(\zeta)$ is WSS

Solution

1. $\mu_x = \frac{1}{2}$: constant
2. $r_x(n_1, n_2) = \frac{1}{3}$: constant
3. $\Longrightarrow$ $X(t) = A(\zeta)$ is WSS

1. Its mean is a constant independent of n, that is,

$$\mathbb{E}\big[x(n)\big] = \mu_x$$

2. Its variance is also a constant independent of n, that is

$$\text{var}\big\{x(n)\big\} = \sigma_x^2$$

3. Its autocorrelation depends only on the distance $\ell = n_1 - n_2$, called the lag, that is

$$r_x(n_1, n_2) = r_x(n_1 - n_2) = r_x(\ell) = \mathbb{E}\big[x(n)x^*(n+l)\big] = \mathbb{E}\big[x(n+\ell)x^*(n)\big]$$

A random process $x(n)$ is wide-sense stationary (WSS) if:

1. Its mean is a constant independent of n, that is,

$$\mathbb{E}\big[x(n)\big] = \mu_x$$

2. Its variance is also a constant independent of n, that is

$$\mathrm{var}\big\{x(n)\big\} = \sigma_x^2$$

3. Its autocorrelation depends only on the distance $\ell = n_1 - n_2$, called the lag, that is

$$r_x(n_1, n_2) = r_x(n_1 - n_2) = r_x(\ell) = \mathbb{E}\big[x(n)x^*(n+l)\big] = \mathbb{E}\big[x(n+\ell)x^*(n)\big]$$

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1. Its mean is a constant independent of n, that is,

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3. Its autocorrelation depends only on the distance $\ell = n_1 - n_2$, called the lag, that is

$$r_x(n_1, n_2) = r_x(n_1 - n_2) = r_x(\ell) = \mathbb{E}\big[x(n)x^*(n+l)\big] = \mathbb{E}\big[x(n+\ell)x^*(n)\big]$$

Mean Sense (M.S.) Ergodic in the Mean:

1. A random process $x(n)$ is ergodic in the mean, i.e. M.S. ergodic, if

$$\langle x(n) \rangle = \mathbb{E}[x(n)] = \mu_x = \frac{1}{2N+1} \sum_{-N}^{N} x(n)$$

2. A random process $x(n)$ is ergodic in the mean, i.e. M.S. ergodic, if

$$\langle x(n) \rangle = \mathbb{E}[x(n)] = \mu_x = \frac{1}{2N+1} \sum_{-N}^{N} x(n)$$

3. A random process $x(n)$ is ergodic in the mean, i.e. M.S. ergodic, if

$$\langle x(n) \rangle = \mathbb{E}[x(n)] = \mu_x = \frac{1}{2N+1} \sum_{-N}^{N} x(n)$$

A random process $x(n)$ is wide-sense stationary (WSS) if:

1. Its mean is a constant independent of n, that is,

$$\mathbb{E}[x(n)] = \mu_x$$

2. Its variance is also a constant independent of n, that is

$$\mathrm{var}\{x(n)\} = \sigma_x^2$$

3. Its autocorrelation depends only on the distance $\ell = n_1 - n_2$, called the lag, that is

$$r_x(n_1, n_2) = r_x(n_1 - n_2) = r_x(\ell) = \mathbb{E}[x(n)x^*(n+l)] = \mathbb{E}[x(n+\ell)x^*(n)]$$

Mean Sense (M.S.) Ergodic in the Mean:

1. A random process $x(n)$ is ergodic in the mean, i.e. M.S. ergodic, if

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$$\langle x(n) \rangle = \mathbb{E}[x(n)] = \mu_x = \frac{1}{2N+1} \sum_{-N}^{N} x(n)$$

3. A random process $x(n)$ is ergodic in the mean, i.e. M.S. ergodic, if

$$\langle x(n) \rangle = \mathbb{E}[x(n)] = \mu_x = \frac{1}{2N+1} \sum_{-N}^{N} x(n)$$

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14 Code Listing and Function/Script Definition Examples

14.1 : Code Listing Examples

14.1.1 Inline Terminal/Command Box Examples

```
cd Documents
```

```
> cd Documents
```

```
git pull --rebase
```

`> cd "My Documents"` changes to directory `My Documents`.

`> dir /A` lists the directory content.

`> copy example.txt d:\target` copies `example.txt` to `d:\target`.

14.1.2 Matlab/Terminal Box Examples

Matlab Listing 1: hello

```
function [R, rx, d, c] = NewtonAlg( ax, bx, mu, N, var_w )
    Q = length(bx)-1;                   % # of highest term of the form w(n-Q)
    P = length(ax)-1;                   % # of highest term of the form x(n-P)

    % Calculate the autocorrelation, spectrum, and cross-correlation
    [R, rx, d] = model2PSD( ax, bx, var_w );
    lambda = eig(R)';                   % Calculate eigenvalues of R

    Rinv = inv(R);                      % Inverse of R
```

```
    gradP = -d;                         % Gradient of P(c)
    c0 = zeros(P,1);                    % Initial value of coefficients
    c = zeros(2,N);                     % Initialize coefficient vectors
    c(:,1) = -mu * Rinv * gradP;  % Calculate coefficients at k=1

    % Calculate gradient of P(c) and use it to calculate the coefficient
    % vector at each iteration of Newton algorithm
    for k = 2:N
        gradP = R * c(:, k-1) - d;
        c(:,k) = c(:, k-1) - mu * Rinv * gradP;
    end
    c = [c0,c];                         % Add initial values to vector c
end
```

Matlab Listing 1 : Matlab implementation of Newton-type algorithm for $(a_1, a_2) = (-1.5955, 0.95)$ and $\mu = 0.1$.

```
>    cd figure
>    mkdir commit -am
```

The option '-a' automatically stages all tracked/modified files before the commit. This can be combined with the message option '-m'.

Matlab Listing 2: hello

```
function [R, rx, d, c] = NewtonAlg( ax, bx, mu, N, var_w )
    Q = length(bx)-1;                   % # of highest term of the form w(n-Q)
    P = length(ax)-1;                   % # of highest term of the form x(n-P)

    % Calculate the autocorrelation, spectrum, and cross-correlation
    [R, rx, d] = model2PSD( ax, bx, var_w );
    lambda = eig(R)';                   % Calculate eigenvalues of R

    Rinv = inv(R);                      % Inverse of R
    gradP = -d;                         % Gradient of P(c)
    c0 = zeros(P,1);                    % Initial value of coefficients
```

```
    c = zeros(2,N);                 % Initialize coefficient vectors
    c(:,1) = -mu * Rinv * gradP;    % Calculate coefficients at k=1

    % Calculate gradient of P(c) and use it to calculate the coefficient
    % vector at each iteration of Newton algorithm
    for k = 2:N
        gradP = R * c(:, k-1) - d;
        c(:,k) = c(:, k-1) - mu * Rinv * gradP;
    end
    c = [c0,c];                     % Add initial values to vector c
end
```

Matlab Listing 2 : Matlab implementation of Newton-type algorithm for $(a_1, a_2) = (-1.5955, 0.95)$ and $\mu = 0.1$.

Matlab Listing 3

```
function [R, rx, d, c] = NewtonAlg( ax, bx, mu, N, var_w )
    Q = length(bx)-1;               % # of highest term of the form w(n-Q)
    P = length(ax)-1;               % # of highest term of the form x(n-P)

    % Calculate the autocorrelation, spectrum, and cross-correlation
    [R, rx, d] = model2PSD( ax, bx, var_w );
    lambda = eig(R)';               % Calculate eigenvalues of R

    Rinv = inv(R);                  % Inverse of R
    gradP = -d;                     % Gradient of P(c)
    c0 = zeros(P,1);                % Initial value of coefficients
    c = zeros(2,N);                 % Initialize coefficient vectors
    c(:,1) = -mu * Rinv * gradP;    % Calculate coefficients at k=1

    % Calculate gradient of P(c) and use it to calculate the coefficient
    % vector at each iteration of Newton algorithm
    for k = 2:N
        gradP = R * c(:, k-1) - d;
        c(:,k) = c(:, k-1) - mu * Rinv * gradP;
    end
```

```
    c = [c0,c];                    % Add initial values to vector c
end
```

Matlab Listing 3 : Matlab implementation of Newton-type algorithm for $(a_1, a_2) = (-1.5955, 0.95)$ and $\mu = 0.1$.

Terminal Listing 2

```
>    cd figure
>    dir commit
>    rmdir myfolder
>    cp demofile demofile bak
>    rm commit -a
>    mv rmfbf sffsknb
>    mkdir commit -am
```

The option '-a' automatically stages all tracked and modified files before the commit. This can be combined with the message option '-m' as seen in the third line.

Terminal Listing 3: hello

```
>    cd figure
>    dir commit
>    rmdir myfolder
>    cp demofile demofile bak
>    rm commit -a
>    mv rmfbf sffsknb
>    mkdir commit -am
```

The option '-a' automatically stages all tracked and modified files before the commit. This can be combined with the message option '-m' as seen in the third line.

```
>    mkdir commit -am
```

The option '-a' automatically stages all tracked/modified files before the commit. This can be combined with the message option '-m'.

```
>    mkdir commit -am
```

14.2 : Script/Function Definition Examples

BASH SCRIPTS

Contents:

.bash_profile

Description: — Generic bash profile pCT users can use for shell sessions on Kodiak/Tardis. This sources the `load_pct_functions.sh` script and loads its bash functions, variables, and aliases/shortcuts so (1) these can be used to perform the host dependent and session setup tasks during user login and (2) they are made available to the pCT user during their shell session

load_pct_functions.sh

Description: — Loads the bash functions, variables, and aliases/shortcuts useful to pCT users on Kodiak/Tardis. This is then sourced by the `.bash_profile` (provided separately) so (1) these can be used to perform the host dependent and session setup tasks during user login and (2) they are made available to the pCT user during their shell session

link_raw_data.sh [–h] [–p <data path>] [–i <angle interval>]

Description: – Generates soft data links to raw data files (`/ion/pCT_data/raw_data/<run_date>`) for a particular run date and organizes these in the `/ion/pCT_data/organized_data` directory by phantom name according to the standardized naming/organizational scheme

Options:	**Option Details:**
-h	– print help to terminal
-p	– path to source raw data (DEFAULT: current working directory
-i	– set angle interval [°] between data files (DEFAULT: **4**°)

link_projection_data.sh [–h] [–p <data path>] [–i <angle interval>] [–EGT <data type>]

Description: – Generates soft data links to preprocessed data files (`/ion/pCT_data/preprocessed_data/<run_date>`) for a particular run date and organizes these in the `/ion/pCT_data/organized_data` directory by phantom name according to the standardized naming/organizational scheme

Options:	**Option Details:**
-h	– print help to terminal
-p	– path to source preprocessed data (DEFAULT: current working directory
-i	– set angle interval [°] between data files (DEFAULT: 4 [°])
-E	– Experimental data flag (DEFAULT)
-G	– GEANT4 data flag
-T	– TOPAS data flag

stage_preprocessed_data.sh

USAGE : [–h]v [–O] [–d <preprocess data>] [–p <readme/data path>] [–f <readme.txt filename>]

Description: — Used to stage preprocessed data with naming/organization appropriate for immediate sharing by specifying the location of the `preprocessed_data` and corresponding `readme.txt` file from which the phantom name, run #/tag(s), and projection angle can be parsed

Options: **Option Details:**

- **-h** — print help to terminal
- **-v** — verbose flag: terminal output 'on' (DEFAULT: $verbose_flag)
- **-d** — date of preprocessing (DEFAULT: $preprocessed_date (today))
- **-p** — path to data and `readme.txt` text file (DEFAULT: $preprocessed_path)
- **-f** — filename of `readme.txt` text file (DEFAULT: $filename)
- **-O** — specifies old date format MMDDYYYY is used (DEFAULT: 'YY-MM-DD' format)

rename-files.sh [–h] [$1 <angle interval>]

Description: — Rename preprocessed data files in current folder, changing each file with `.dat.root.reco.root.bin` extension to "*projection_xxx.bin*" for each angle `xxx`

Options: **Option Details:**

- **-h** — print help to terminal
- **$1** — angle interval between preprocessed data files (DEFAULT: 4 [°])

BASH FUNCTIONS

Contents:

Description of bash functions supplied in pCT_Tools repository and their optional/required parameters and usage

add_rcode_repo

USAGE : [–h] [–u <username>] [–a <git account>] [–r <git repo>]

Description: – add GitHub repository to a user's code directory on Tardis

Options: **Option Details:**

- **-h** – print help to terminal
- **-u** – username (DEFAULT: $username)
- **-a** – git account (DEFAULT: $account)
- **-r** – git repository (DEFAULT: $repo)

set_rcode
USAGE : [–h] [–G] [–g] [–a <git account>] [–r <git repo>] [–b <git branch>] [–u <username>]

Description:	– select the GitHub repository corresponding to the code that the user currently wishes to work with and compile/run, if a user copy should be cloned or the code is to be taken directly from the primary clone to a user's code directory on Tardis
Options:	**Option Details:**
-h	– print help to terminal
-G	– reconstruction group username flag (DEFAULT: $username)
-g	– global git code repositories flag (DEFAULT: user git code directories)
-a	– git account (DEFAULT: $account)
-r	– git repository (DEFAULT: $repo)
-b	– git branch (DEFAULT: $branch)
-u	– username, if applicable (DEFAULT: $username)

nvccgen
USAGE : [–h] [$1 <arch>] [$2 <code>]

Description:	– compile pCT_Reconstruction code with argument #1/#2 used to set architecture/code
Options:	**Option Details:**
-h	– print help to terminal
$1	– NVCC architecture specification # (`35` used in `compute_35`
$2	– NVCC code specification # (i.e. `35` used in `sm_35`)

runrecon

USAGE : [–h] [$1 <arch>] [$2 <code>]

Description:	– compile and run pCT_Reconstruction code with argument #1/#2 used to set architecture/code
Options:	**Option Details:**
-h	– print help to terminal
$1	– NVCC architecture specification # (`35` used in `compute_35`
$2	– NVCC code specification # (i.e. `35` used in `sm_35`)

construct_recon_path

USAGE : [–hv] [–EGT] [–IO] [–o x] [–r x] [–n x] [–d x] [–D x]

Description: – construct input or output data path for appropriately organized reconstruction data

Options: **Option Details:**

- **-h** – print help to terminal
- **-v** – verbose console output on (DEFAULT: 'off')
- **-o** – object name (REQUIRED)
- **-r** – run date (REQUIRED)
- **-n** – run # + tag(s) (REQUIRED)
- **-d** – preprocessed date (DEFAULT: today)
- **-D** – reconstruction date, if applicable (DEFAULT: today)
- **-E** – Experimental data flag (DEFAULT)
- **-G** – GEANT4 data flag
- **-T** – TOPAS data flag
- **-I** – input data flag
- **-O** – output data flag

construct_preprocessing_path

USAGE : [–hv] [–EGT] [–IO] [–o x] [–r x] [–n x] [–d x] [–D x]

Description: – construct input or output data path for appropriately organized preprocessing data

Options: **Option Details:**

- **-h** – print help to terminal
- **-v** – verbose console output on (DEFAULT: 'off')
- **-o** – object name (REQUIRED)
- **-r** – run date (REQUIRED)
- **-n** – run # + tag(s) (REQUIRED)
- **-d** – preprocessed date (DEFAULT: today)
- **-E** – Experimental data flag (DEFAULT)
- **-G** – GEANT4 data flag
- **-T** – TOPAS data flag
- **-I** – input data flag
- **-O** – output data flag

construct_pct_path

USAGE : [–hv] [–PR] [–EGT] [–IO] [–o x] [–r x] [–n x] [–d x] [–D x]

Description: – construct input or output data path for appropriately organized preprocessing or reconstruction data

Options:	**Option Details:**
-h	– print help to terminal
-v	– verbose console output on (DEFAULT: 'off')
-P	– preprocessed data flag (DEFAULT: preprocessing)
-R	– reconstruction data flag (DEFAULT)
-o	– object name (REQUIRED)
-r	– run date (REQUIRED)
-n	– run # + tag(s) (REQUIRED)
-d	– preprocessed date (DEFAULT: today)
-D	– reconstruction date, if applicable (DEFAULT: today)
-E	– Experimental data flag (DEFAULT)
-G	– GEANT4 data flag
-T	– TOPAS data flag
-I	– input data flag
-O	– output data flag

organize_data

USAGE : [–hv] [–PR] [–MC] [–EGT] [–IO] [–p x] [–t x] [–o x] [–r x] [–n x] [–d x] [–D x]

Description: – move or copy input/output preprocessing or reconstruction data into an appropriately named/organized hierarchy of directories, with the root of the hierarchy written to the specified/default output data path.

Options:	**Option Details:**
-h	– print help to terminal
-v	– verbose console output on (DEFAULT: 'off')
-P	– preprocessed data flag (DEFAULT: preprocessing)
-R	– reconstruction data flag (DEFAULT: preprocessing)
-M	– move data (DEFAULT: copy)
-C	– copy data (DEFAULT: copy)
-p	– path to data (DEFAULT: current working directory)
-t	– write output hierarchy to (DEFAULT: current working directory)
-o	– object name (REQUIRED)
-r	– run date (REQUIRED)
-n	– run # + tag(s) (REQUIRED)
-d	– preprocessed date (DEFAULT: today)
-D	– reconstruction date, if applicable (DEFAULT: today)
-E	– Experimental data flag (DEFAULT)
-G	– GEANT4 data flag
-T	– TOPAS data flag
-I	– input data flag
-O	– output data flag

add_tardis_data DETAILS:

Ubiquitous Usage: — Use these options to specify the path to the data to be copied to Tardis, the destination Tardis node, and if its organized/unorganized.

Options:	**Option Details:**
-h	— print help to terminal
-v	— verbose console output on (DEFAULT: 'off')
-p	— path to data (DEFAULT: current working directory)
-U	— unorganized data flag (DEFAULT: organized)
-H	— organized data heirarchy flag (DEFAULT)
-N	— destination Tardis node number (3-5) (DEFAULT: '3')

Organized Data: — The default option values are set such that when organized data is specified, this organized data is automatically copied to the corresponding organized data directory on Tardis without additional user input

---

Unorganized Data: — Specify if the unorganized data should be organized first or copied to a user's unorganized data directory on Tardis

Options:	**Option Details:**
-F	— organize data before transfer (DEFAULT: false)

(*i*) Organize First: — Organize data first and copy to organized data directory on Tardis (requires path to data and specification of information needed to organize the data)

Options:	**Option Details:**
-P	— preprocessed data flag (DEFAULT: preprocessing)
-R	— reconstruction data flag (DEFAULT)
-M	— move data (DEFAULT: copy)
-C	— copy data (DEFAULT: copy)

-t	– destination Kodiak path for pre-organized data (DEFAULT: $PWD)
-o	– object name (REQUIRED)
-r	– run date (REQUIRED)
-n	– run # + tag(s) (REQUIRED)
-d	– preprocessed date (DEFAULT: today)
-D	– reconstruction date, if applicable (DEFAULT: today)
-E	– Experimental data flag (DEFAULT)
-G	– GEANT4 data flag
-T	– TOPAS data flag
-I	– input data flag
-O	– output data flag

***(ii)* Copy Direct:** – Copy unorganized data to user's unorganized data directory on Tardis in a subdirectory specified by the user (requires path to data, specify desired subdirectory of user_data on Tardis)

Options:	**Option Details:**
-t	– subdirectory of unorganized data on Tardis (DEFAULT: $PWD)

15.1 : Inline Text Boxes

Nomenclature Entry

Nomenclature Entry

Nomenclature Entry

Nomenclature Entry

Nomenclature Entry

15.2 : Itemized Text Boxes

personal

- One
- Two
- Three
- Four
- Five

15.3 : Definition Text Boxes

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Definition 15.3.1 Title Here

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Definition 15.3.2 Title Here

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15.4 : Definition/Theorem/Corollary/Lemma Title Boxes

Theorem 15.4.1: Mittelwertsatz n Variable

Es sei $n \in \mathbb{N}$, $D \subseteq \mathbb{R}^n$ eine offene Menge und $f \in C^1(D, \mathbb{R})$. Dann gibt es auf jeder Strecke $[x_0, x] \subset D$ einen Punkt $\xi \in [x_0, x]$, so dass gilt

$$f(x) - f(x_0) = \operatorname{grad} f(\xi)^\top (x - x_0)$$

Corollary 15.4.2: Mittelwertsatz n Variable

Es sei $n \in \mathbb{N}$, $D \subseteq \mathbb{R}^n$ eine offene Menge und $f \in C^1(D, \mathbb{R})$. Dann gibt es auf jeder Strecke $[x_0, x] \subset D$ einen Punkt $\xi \in [x_0, x]$, so dass gilt

$$f(x) - f(x_0) = \operatorname{grad} f(\xi)^\top (x - x_0)$$

Definition 15.4.3: Mittelwertsatz n Variable

Es sei $n \in \mathbb{N}$, $D \subseteq \mathbb{R}^n$ eine offene Menge und $f \in C^1(D, \mathbb{R})$. Dann gibt es auf jeder Strecke $[x_0, x] \subset D$ einen Punkt $\xi \in [x_0, x]$, so dass gilt

$$f(x) - f(x_0) = \operatorname{grad} f(\xi)^\top (x - x_0)$$

Lemma 15.4.4: Mittelwertsatz n Variable

Es sei $n \in \mathbb{N}$, $D \subseteq \mathbb{R}^n$ eine offene Menge und $f \in C^1(D, \mathbb{R})$. Dann gibt es auf jeder Strecke $[x_0, x] \subset D$ einen Punkt $\xi \in [x_0, x]$, so dass gilt

$$f(x) - f(x_0) = \operatorname{grad} f(\xi)^\top (x - x_0)$$

15.5 : Definition/Theorem/Corollary/Lemma Boxes

Theorem 15.5.1: Mittelwertsatz n Variable

Es sei $n \in \mathbb{N}$, $D \subseteq \mathbb{R}^n$ eine offene Menge und $f \in C^1(D, \mathbb{R})$. Dann gibt es auf jeder Strecke $[x_0, x] \subset D$ einen Punkt $\xi \in [x_0, x]$, so dass gilt

$$f(x) - f(x_0) = \operatorname{grad} f(\xi)^\top (x - x_0)$$

Corollary 15.5.2: Nullstellenexistenz

Ist $f[a,b] \to \mathbb{R}$ stetig und haben $f(a)$ und $f(b)$ entgegengesetzte Vorzeichen, also $f(a)f(b) < 0$, so besitzt f eine Nullstelle $x_0 \in]a,b[$, also $f(x_0) = 0$.

$$f(x) - f(x_0) = \operatorname{grad} f(\xi)^\top (x - x_0)$$

Definition 15.5.3: Differenzierbarkeit

Eine Funktion $f\ I \to \mathbb{R}$ auf einem Intervall I heißt in $x_0 \in I$ differenzierbar oder linear approximierbar, wenn der Grenzwert

$$\lim_{x \to x_0} \frac{f(x) - f(x_0)}{x - x_0} = \lim_{h \to 0} \frac{f(x_0 + h) - f(x_0)}{h}$$

existiert. Bei Existenz heißt dieser Grenzwert Ableitung oder Differential quotient von f in x_0 und man schreibt für ihn

$$f'(x_0) \quad \textit{oder} \quad \frac{df}{dx}(x_0).$$

Lemma 15.5.4: Mittelwertsatz n Variable

Es sei $n \in \mathbb{N}$, $D \subseteq \mathbb{R}^n$ eine offene Menge und $f \in C^1(D, \mathbb{R})$. Dann gibt es auf jeder Strecke $[x_0, x] \subset D$ einen Punkt $\xi \in [x_0, x]$, so dass gilt

$$f(x) - f(x_0) = \operatorname{grad} f(\xi)^\top (x - x_0)$$

csvgroup of 'tcolorbox' option csvlists :

16.5.1 'tcolorbox' tcbset components/styles testing

'tcolorbox' style component testing :

borderoutline

Hello, here is some text without a meaning.This text should show what a printed text will look like at this place.If you read this text, you will get no information. Really? Is there no information?Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all!

doubleborderoutline

Hello, here is some text without a meaning.This text should show what a printed text will look like at this place.If you read this text, you will get no information. Really? Is there no information?Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all!

@tcb@outline@title

Hello, here is some text without a meaning.This text should show what a printed text will look like at this place.If you read this text, you will get no information. Really? Is there no information?Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all!

@tcb@dash@frame

Hello, here is some text without a meaning.This text should show what a printed text will look like at this place.If you read this text, you will get no information. Really? Is there no information?Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all!

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Hello, here is some text without a meaning.This text should show what a printed text will look like at this place.If you read this text, you will get no information. Really? Is there no information?Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all!

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Hello, here is some text without a meaning.This text should show what a printed text will look like at this place.If you read this text, you will get no information. Really? Is there no information?Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all!

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@tcb@outline@frame

Hello, here is some text without a meaning.This text should show what a printed text will look like at this place.If you read this text, you will get no information. Really? Is there no information?Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all!

tcbdoubleoutline

Hello, here is some text without a meaning.This text should show what a printed text will look like at this place.If you read this text, you will get no information. Really? Is there no information?Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all!

tcbframeoutlinebox

Hello, here is some text without a meaning.This text should show what a printed text will look like at this place.If you read this text, you will get no information. Really? Is there no information?Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all!

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Hello, here is some text without a meaning.This text should show what a printed text will look like at this place.If you read this text, you will get no information. Really? Is there no information?Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all!

functionarglist testing :

[–h] [–G] [–g] [–IO] [–a <git account>] [–r <git repo>] [–b <git branch>] [–u <username>]
functionarglist= [–h] [–G] [–g] [–IO] [–a <git account>] [–r <git repo>] [–b <git branch>] [–u <username>]
functionarglist*= @@functionargs=[–h][–G][–g][–IO][–a <git account>][–r <git repo>][–b <git branch>][–u <username>]

'tcolorbox' "tcbset testing :

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Part IV

Package Usage Examples

Key:

Green : directories whose names do not change
Brown : directories w/ parameter dependent naming (e.g. object name, date, etc.)
Italic + Royal Blue : data/image file
Italic + Dark Blue : set of data/image files

17.1 : Kodiak Directories

Description and purpose/usage of the private user and shared directories on Kodiak

Kodiak

/ion/...

This is the parent directory for all pCT code and data on the network-attached storage device mounted directory is dedicated to the storage of all files associated with proton and ion therapy research. There are private and shared subdirectories and to prevent inappropriate modifications/deletions of shared code/data, users only have write permissions to their private directories and they cannot directly add/modify shared data. To share data with the collaboration, users submit the data to their private "staging" directory using the appropriate naming/organization and an administrator will then validate the data and move it to the appropriate shared directory. Administrators typically will not be familiar with the naming/organizational scheme, but by organizing the data according to the full destination path, administrators can move the entire hierarchy of files/folders directly to /ion, thereby merging the contents of any existing directories automatically.

The data in this directory is located on a network storage device and can be accessed from all Kodiak and Tardis cluster nodes. The device is also backed up to tape drive periodically to prevent permanent loss of

data in the event of drive failure.

/ion/home/<*username*>/...

– This is a user's private home directory where the files associated with their account are stored (e.g., *.bash_profile*, *.bash_history*, etc.) and is the default login directory. Each user only has access to their personal directory, but because it is on the network storage device, it can be accessed from each of the Kodiak/Tardis nodes. Now that the home directories have been moved to /ion, they no longer have a limited storage capacity, so users may run code and write the resulting output data/images to this directory. Note that as a subdirectory of /ion, the data in this directory will automatically be backed up to tape drive so it is recoverable in case of data corruption or drive failure.

/data/<*username*>/...

– These private data directories can be used as an alternative to /ion/home/<*username*> for storing input data for code/program execution and as the destination for the resulting output data generated. As subdirectories of / data, the contents of these directories are backed up periodically, so these can also be used for long term data storage.

/ion/incoming/<*username*>/...

– These private directories are used to upload data to the Baylor server prior to moving it to the intended destination. When the uploaded data is intended to be shared with the collaboration, the directory should be used to rename and organize the data files according to the naming/organizational scheme before moving it to a user's private /staging directory, from which an administrator will validate and move the data to the appropriate shared directory.

/ion/staging/<*username*>/...

– These directories are used to submit code/data for sharing with the collaboration. Since administrators are typically unfamiliar with the naming/organizational scheme for shared data, users must first rename/organize the data as needed to create the entire hierarchy of directories corresponding to the full destination path, including all subdirectories below /ion. Administrators need not know the destination path or understand the organization but can then simply move the entire hierarchy and the contents of existing directories such as /ion will automatically be merged and the new data/directories added. To simplify the creation of these hierarchies and ensure consistency by removing manual naming/organization, bash scripts/functions

have been developed to organize data and move it to a user's /staging directory by passing the requisite information as execution parameters (e.g., phantom, run date/#/tag(s), etc.).

/ion/pCT_data/...

– This directory is where the raw, preprocessed, projection, and reconstruction data/images are moved to make them available to the other pCT users. Each type of data is stored in separate subdirectories and soft links to this data are created and organized in a directory hierarchy indicating their input/output data dependencies. The directory/file naming and organizational scheme for each type of data and the soft links are outlined in the next section of this document. Data/images should only be moved to this shared directory after having been verified as valid/accurate and having been organized appropriately.

/ion/pCT_data/pCT_Documentation/...

– Documentation relevant to pCT is stored in this directory, such as descriptions of the data format, coordinate system, and phantoms and pCT related publications (including student theses/dissertations). This is a GitHub managed local repository allowing everyone to "*push*" contributions to the repository and "*pull*" updates/additions from others into their own local clone ensuring everyone has access to the latest information.

/ion/pCT_code/...

– This directory is used to store permanent and semi-permanent pCT source code, from data acquisition to image reconstruction and analysis of reconstructed images. It contains clones of GitHub repositories as well as user's personal versions of programs they want to make available to other users (otherwise users should keep their code in their private directories) organized by program type (Preprocessing/Reconstruction/etc.) with subdirectories for each user.

/ion/pCT_code/git/<*GitHub account*>/<*GitHub repository*>/...

– This directory contains clones of the available pCT GitHub accounts and repositories, with parent directories for each GitHub account and subdirectories for each of their repositories. Each program repository has a `master` branch, which typically corresponds to the current release version (though there may also be a branch like `release` used instead) and each of the program's developers will typically have their own branch which they can use to develop and test new ideas/features. The group of developers of a program should

decide amongst themselves what the process will be for approving merges with the `master/release` branch and when to release a new version of the program, which may include the results of several separate merges.

Users accessing the `master/release` branch of these clones should execute `git pull --rebase` prior to using the code to ensure it is updated to its latest version.

NOTE: This should not be done for other branches or the personal versions of code.

/ion/pCT_code/user_code/<*username*>/...

– Contains subdirectories for each pCT user where they can store and modify clones of the pCT program repositories and their personal code.

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CFRIP,OWD,OWD,OWD,OWD,OWD's,OWD's,OWDs
MFA etc

17.2 : Tardis Directories

Description and purpose/usage of the private user and shared directories on the Tardis compute nodes

Tardis

/local/...

– This is the parent directory for all pCT code and data on each Tardis compute node's local solid-state drive, the equivalent of the /ion directory on Kodiak's network attached storage device. This data is stored on the compute nodes' local solid-state drive and is not backed up, so users must ensure they copy data to Kodiak if they want to store it permanently

/local/pCT_code/...

– This directory is used to store pCT code on the Tardis compute nodes and corresponds to the /ion/pCT_code directory on Kodiak (with the same organizatioal scheme as well).

/local/pCT_code/user_code/<*username*>/...

– The equivalent of Kodiak's /ion/pCT_code/user_code/<*username*>/... subdirectories where pCT users can copy/modify/execute their personal clones of pCT program repositories and their personal code on Tardis compute nodes

/local/pCT_code/git/<*GitHub account*>/<*GitHub repository*>/...

– This directory contains clones of the available pCT GitHub accounts and repositories, with parent directories for each GitHub account and subdirectories for each of their repositories. Each program repository has a `master` branch, which typically corresponds to the current release version (though there may also be a branch like `release` used instead) and each of the program's developers will typically have their own branch which they can use to develop and test new ideas/features. The group of developers of a program should decide amongst themselves what the process will be for approving merges with the `master/release` branch and when to release a new version of the program, which may include the results of several separate merges.

Users accessing the master/release branch of these clones should execute `git pull --rebase` prior to using the code to ensure it is updated to its latest version.

NOTE: This should not be done for other branches or the personal versions of code.

/local/pCT_data/...

– This directory is where pCT data is to be copied from Kodiak and corresponds to the /ion/pCT_data directory on Kodiak.

/local/pCT_data/user_data/<*username*>/...

– Subdirectories for each pCT user on each Tardis compute node where they can transfer data they want to reconstruct when the data is not organized according to the pCT data naming/organizational scheme. If the output data they generate will also be unorganized, it should also be written to this directory.

NOTE: The /pCT-collaboration/pCT_Tools repository contains a script which loads a number of bash functions useful to pCT users, including a function that can be used to organize and then copy unorganized data to the organized data directory on the Tardis compute nodes

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and then and then and then and then and then and then and then and then and then
MFA etc

18.1 : Code Organization

18.1.1 pCT_Code Hierarchy

pCT_code

/ion/local/pCT_code/...

– directory on Kodiak and each Tardis compute node used to store clones of the GitHub repositories relevant to pCT and the private storage of user code. The naming and organizational scheme is the same on Kodiak and each Tardis compute node, thereby simplifying distribution of code for execution on Tardis; the only difference is the top level parent directory on Kodiak is /ion and on the Tardis compute nodes it is /local, but their subdirectories are identical. See the GitHub Accounts/Repositories section for a list of GitHub accounts and repositories relevant to pCT. For a visual representation of this hierarchy, see the pCT_code Hierarchy Diagram.

(1) /ion or /local : parent directory for all pCT code/data on Kodiak and the Tardis compute nodes

- **(a) /pCT_code : directory containing the code for all pCT programs linked to their GitHub repositories as well as subdirectories for each pCT user where they can clone and modify these repositories and store/execute their own code**
  - **(i) /git : directory containing clones of the standard/common pCT programs, providing easy and immediate access to the newest version of each of these programs**
    - **(1) /<*GitHub account*> : directories for each of the GitHub accounts containing one or more pCT**

programs

(a) /<*GitHub repository*> : subdirectories for each pCT code repository in the associated GitHub account

(ii) /user_code : directory containing subdirectories for each user where they can store their personal code

(1) /<*username*> : subdirectories for each pCT user where they can store their personal code

18.2 : Data Organization

18.2.1 organized_data Hierarchy

ORGANIZED_DATA

/ion/pCT_data/organized_data

– directory containing all raw, preprocessed/projection, and reconstruction data files, primarily soft symbolic links to the actual data stored elsewhere by data type, organized into a hierarchy of directories indicating data dependencies. A visual representation of this hierarchy can be seen in the organized_data Hierarchy Diagram. Reconstruction can optionally generate a number of additional data files containing intermediate data useful in debugging and analysis, but only the default data/image files are shown here for brevity (see the Reconstruction File List section for a full list of reconstruction data/image files).

(1) /Phantom : directory containing all of the experimental/simulated data and reconstructed images associated with this phantom/object.

(a) /Reference_Images : directory containing reference images (xCT, RSP, etc) relevant to analysis/comparison of the data/images for this object and data type.

(b) /Experimental : directory containing data and images generated from experimental scans of the object.

(i) /YY-MM-DD : directory containing data and reconstructed images corresponding to the experimental

scan of the object performed on this date.

(1) /XXXX[_AAA] : directory containing data/images corresponding to the 4-digit run # "*XXXX*", potentially including *"subcategory tag(s)"* of the form "*_AAA*" indicating, e.g., a continuous scan ("*_Cont*"), phantom position/section (inferior ("*_Inf*") or superior ("*_Sup*"), top ("*_Top*") or bottom ("*_Bot*"), etc.).

(a) /Input : directory containing raw data generated by object scan from each gantry angle and transmitted by event builder.

(i) *raw_xxx.bin* : binary files containing trigger/tracker/energy detector data from event builder associated with gantry angle "*xxx*" ={"*001*", "*002*", "*003*", ···}.

(b) /Output : directory containing calibration and post processed data generated from analysis of raw data and used as input to image reconstruction.

(i) /YY-MM-DD : directory containing the post processed "*projection_xxx.bin*" data generated on this date and the reconstructions using this data.

(1) *readme.txt* : contains input raw data info, phantom name, and run date.

(2) *TVcorr.txt* : contains TV corrected WEPL calibration curve coefficients.

(3) *WcalibTemp.txt* : temporary file containing WEPL calibration curve coefficients.

(4) *Wcalib.txt* : contains final WEPL calibration curve coefficients.

(5) *projection_xxx.bin* : preprocessed data files containing tracker coordinates and WEPL data for gantry angle "*xxx*" = {"*001*", "*002*", "*003*", ···} used as input to image reconstruction.

(6) /Reconstruction : directory containing preprocessed data and reconstructed images generated using the "*projection_xxx.bin*" data along with reference images relevant to the object.

(a) *settings.cfg* : configuration file containing key/value pairs specifying scan/phantom properties (phantom, run date/#/tag(s), etc.) and default reconstruction settings/-parameters.

(b) /YY-MM-DD : directory containing the preprocessed data generated on this date and the reconstructed images generated from this data.

(i) *execution_log.txt* : execution times for various portions of preprocessing and/or reconstruction and total program execution time.

(ii) *FBP.txt* : text image of filtered back projection (FBP) image.

(iii) *FBP.png* : conversion of "*FBP.txt*" to PNG image.

(iv) *FBP_med_filtered.txt* : text image result of applying median filter to the filtered back projection (FBP) image.

(v) *FBP_med_filtered.png* : conversion of "*FBP_avg_filtered.txt*" to PNG image.
(vi) *hull.txt* : text image of selected object hull in 1s/0s.
(vii) *hull.png* : conversion of "*hull.txt*" to PNG image.
(viii) *settings_log.cfg* : copy of "*settings.cfg*" with any changes made to parameters/options applied at execution, if any.
(ix) *TV_measurements.txt* : total variation (TV) measurements before/after each iteration
(x) *x_0.txt* : text image of initial iterate.
(xi) *x_0.png* : conversion of "*x_0.txt*" to PNG image.
(xii) /Images : directory containing reconstructed images from the preprocessed data.
(1) /YY-MM-DD : directory containing reconstructed images generated from the preprocessed data on this date.
(a) *x_k.txt* : text image of reconstructed image x^k after k iterations.
(b) *x_k.png* : PNG image of reconstructed image x^k after k iterations.

(c) /Simulated : directory containing data and images generated from simulated scans of the object.
(i) /G_YY-MM-DD : directory containing data and reconstructed images from the GEANT4 simulated scan of the object generated on this date..
(1) /XXXX[_AAA] : directory containing data/images corresponding to the 4-digit run # "*XXXX*", potentially including *"subcategory tag(s)"* of the form "*_AAA*" indicating, e.g., a continuous scan ("*_Cont*"), phantom position/section (inferior ("*_Inf*") or superior ("*_Sup*"), top ("*_Top*") or bottom ("*_Bot*"), etc.).
(a) /Input : directory containing simulated raw data files for each gantry angle.
(i) *raw_xxx.bin* : binary files containing trigger/tracker/energy detector data from event builder associated with gantry angle "*xxx*" = {"*001*", "*002*", "*003*", ···}.
(b) /Output : directory containing calibration and post processed data generated from analysis of raw data and used as input to image reconstruction.
(i) /YY-MM-DD : directory containing the post processed "*projection_xxx.bin*" data generated on this date and the reconstructions using this data.
(1) *readme.txt* : contains input raw data info, phantom name, and run date.
(2) *TVcorr.txt* : contains TV corrected WEPL calibration curve coefficients.
(3) *WcalibTemp.txt* : temporary file containing WEPL calibration curve coefficients.
(4) *Wcalib.txt* : contains final WEPL calibration curve coefficients.

(5) *projection_xxx.bin* : preprocessed data files containing tracker coordinates and WEPL data for gantry angle "*xxx*" = {"*001*", "*002*", "*003*", $\cdots$} used as input to image reconstruction.

(6) /Reconstruction : directory containing preprocessed data and reconstructed images generated using the "*projection_xxx.bin*" data along with reference images relevant to the object.

(a) *settings.cfg* : configuration file containing key/value pairs specifying scan/phantom properties (phantom, run date/#/tag(s), etc.) and default reconstruction settings/-parameters.

(b) /YY-MM-DD : directory containing the preprocessed data generated on this date and the reconstructed images generated from this data.

(i) *execution_log.txt* : execution times for various portions of preprocessing and/or reconstruction and total program execution time.

(ii) *FBP.txt* : text image of filtered back projection (FBP) image.

(iii) *FBP.png* : conversion of "*FBP.txt*" to PNG image.

(iv) *FBP_med_filtered.txt* : text image result of applying median filter to the filtered back projection (FBP) image.

(v) *FBP_med_filtered.png* : conversion of "*FBP_avg_filtered.txt*" to PNG image.

(vi) *hull.txt* : text image of selected object hull in 1s/0s.

(vii) *hull.png* : conversion of "*hull.txt*" to PNG image.

(viii) *settings_log.cfg* : copy of "*settings.cfg*" with any changes made to parameters/options applied at execution, if any.

(ix) *TV_measurements.txt* : total variation (TV) measurements before/after each iteration

(x) *x_0.txt* : text image of initial iterate.

(xi) *x_0.png* : conversion of "*x_0.txt*" to PNG image.

(xii) /Images : directory containing reconstructed images from the preprocessed data.

(1) /YY-MM-DD : directory containing reconstructed images generated from the preprocessed data on this date.

(a) *x_k.txt* : text image of reconstructed image x^k after k iterations.

(b) *x_k.png* : PNG image of reconstructed image x^k after k iterations.

(ii) /T_YY-MM-DD : directory containing data and reconstructed images corresponding to all TOPAS simulated scans of the object generated on this date.

(1) /XXXX[_AAA] : directory containing data/images corresponding to the 4-digit run # "*XXXX*",

potentially including *"subcategory tag(s)"* of the form "*_AAA*" indicating, e.g., a continuous scan ("*_Cont*"), phantom position/section (inferior ("*_Inf*") or superior ("*_Sup*"), top ("*_Top*") or bottom ("*_Bot*"), etc.).

(a) /Input : directory containing simulated raw data files generated for each gantry angle.

(i) *raw_xxx.bin* : binary files containing trigger/tracker/energy detector data from event builder associated with gantry angle $xxx = \{001, "002", 003, \cdots\}$.

(b) /Output : directory containing calibration and post processed data generated from analysis of raw data and used as input to image reconstruction.

(i) /YY-MM-DD : directory containing the post processed "*projection_xxx.bin*" data generated on this date and the reconstructions using this data.

(1) *readme.txt* : contains input raw data info, phantom name, and run date.

(2) *TVcorr.txt* : contains TV corrected WEPL calibration curve coefficients.

(3) *WcalibTemp.txt* : temporary file containing WEPL calibration curve coefficients.

(4) *Wcalib.txt* : contains final WEPL calibration curve coefficients.

(5) *projection_xxx.bin* : preprocessed data files containing tracker coordinates and WEPL data for gantry angle "*xxx*" $= \{"001", "002", "003", \cdots\}$ used as input to image reconstruction.

(6) /Reconstruction : directory containing preprocessed data and reconstructed images generated using the "*projection_xxx.bin*" data along with reference images relevant to the object.

(a) *settings.cfg* : configuration file containing key/value pairs specifying scan/phantom properties (phantom, run date/#/tag(s), etc.) and default reconstruction settings/-parameters.

(b) /YY-MM-DD : directory containing the pre-reconstruction processed data generated on this date and the reconstructed images generated from this data.

(i) *execution_log.txt* : execution times for various portions of preprocessing and/or reconstruction and total program execution time.

(ii) *FBP.txt* : text image of filtered back projection (FBP) image.

(iii) *FBP.png* : conversion of "*FBP.txt*" to PNG image.

(iv) *FBP_med_filtered.txt* : text image result of applying median filter to the filtered back projection (FBP) image.

(v) *FBP_med_filtered.png* : conversion of "*FBP_avg_filtered.txt*" to PNG image.

(vi) *hull.txt* : text image of selected object hull in 1s/0s.

(vii) *hull.png* : conversion of "*hull.txt*" to PNG image.

(viii) *settings_log.cfg* : copy of "*settings.cfg*" with any changes made to parameters/options applied at execution, if any.

(ix) *TV_measurements.txt* : total variation (TV) measurements before/after each iteration

(x) *x_0.txt* : text image of initial iterate.

(xi) *x_0.png* : conversion of "*x_0.txt*" to PNG image.

(xii) /Images : directory containing reconstructed images from the preprocessed data.

(1) /YY-MM-DD : directory containing reconstructed images generated from the preprocessed data on this date.

(a) *x_k.txt* : text image of reconstructed image x^k after k iterations.

(b) *x_k.png* : PNG image of reconstructed image x^k after k iterations.

18.2.2 raw_data Hierarchy

RAW_DATA

/ion/pCT_data/raw_data

– directory where all raw experimental data files from a particular scan are stored in separate directories according to the scan date prior to creation of soft symbolic links named "*projection_xxx.bin*" and organized according to the naming/organizational scheme.

(1) /YY-MM-DD : Folder containing all raw experimental data acquired from the scan beginning on "*YY-MM-DD*"

(a) *<Phantom>_XXXX[_AAA]_xxx.dat* : raw experimental data for the object named "*<Phantom>*", from run # "*XXXX[_AAA]*", where "*XXXX*" is a 4 digit # with leading zeros, "*_AAA*" are optional "*subcategory tag(s)*" indicating, e.g., a continuous scan ("*_Cont*"), phantom position/section (inferior ("*_Inf*") or superior ("*_Sup*"), top ("*_Top*") or bottom ("*_Bot*"), etc.), and "*xxx*" is the gantry angle at which the data was acquired.

18.2.3 preprocessed_data Hierarchy

PREPROCESSED_DATA

/ion/pCT_data/preprocessed_data

– directory containing the preprocessed experimental data organized by scan and processed dates

(1) /YY-MM-DD : Folder containing all processed experimental data corresponding to the raw experimental data acquired on "*YY-MM-DD*"

(a) /YY-MM-DD : Folder containing all processed experimental data generated on "*YY-MM-DD*" from the raw data

(i) *TVcorr.txt* : contains TV corrected WEPL calibration curve coefficients.

(ii) *WcalibTemp.txt* : temporary file containing WEPL calibration curve coefficients.

(iii) *Wcalib.txt* : contains final WEPL calibration curve coefficients.

(iv) *<Phantom>_XXXX[_AAA]_xxx.dat.root.reco.root.bin* : preprocessed experimental data with tracker coordinates, recovery of missing hits when possible, and calibrated WEPL measurements for the object named "*<Phantom>*", from run # "*XXXX[_AAA]*", where "*XXXX*" is a 4 digit # with leading zeros, "*_AAA*" are optional "*subcategory tag(s)*" indicating, e.g., a continuous scan ("*_Cont*"), phantom position/section (inferior ("*_Inf*") or superior ("*_Sup*"), top ("*_Top*") or bottom ("*_Bot*"), etc.), and "*xxx*" is the gantry angle at which the data was acquired.

18.2.4 user_data (Unorganized Data) Hierarchy

USER_DATA

/ion/pCT_data/user_data

– directory containing unorganized input and output reconstruction data, allowing users to use and keep their unorganized data separate from other data and maintain it in their preferred organizational scheme without it interfering with the properly organized data.

(1) /user_data : directory unique to Tardis compute nodes containing subdirectories for each user where they can transfer unorganized data they want to reconstruct and write the corresponding output reconstruction data/images

(a) /<*username*> : subdirectories for each pCT user for the unorganized input and output reconstruction data

18.2.5 reconstruction_data Hierarchy

RECONSTRUCTION_DATA

/ion/pCT_data/reconstruction_data

– directory containing the default data/images generated during reconstruction. Additional data files and images can optionally be written to disk as well and a full list of these is given in the Reconstruction File List section.

(1) *execution_log.csv* : global execution log containing entries with scan/object information and the settings/parameters used in reconstruction for each reconstructions performed to date, with new row entries added each time the reconstruction program is executed.

(2) /Phantom : directory containing all of the experimental/simulated data and reconstructed images associated with this phantom/object.

(a) /Reference_Images : directory containing reference images (xCT, RSP, etc) relevant to analysis/comparison of the data/images for this object and data type.

(b) /Experimental : directory containing data and images generated from an experimental scan of the object.

(i) /YY-MM-DD : directory containing data and reconstructed images corresponding to the experimental scan of the object performed on this date.

(1) /XXXX[_AAA] : directory containing data/images corresponding to the 4-digit run # "*XXXX*", potentially including *"subcategory tag(s)"* of the form "*_AAA*" indicating, e.g., a continuous scan ("*_Cont*"), phantom position/section (inferior ("*_Inf*") or superior ("*_Sup*"), top ("*_Top*") or bottom ("*_Bot*"), etc.).

(a) /Input : directory containing raw data generated by scan of object from each gantry angle and transmitted by event builder.

(i) *raw_xxx.bin* : binary files containing trigger/tracker/energy detector data from event builder associated with gantry angle "*xxx*" ={"*001*", "*002*", "*003*", $\cdots$}.

(b) /Output : directory containing calibration and post processed data generated from analysis of raw data and used as input to image reconstruction.

(i) /YY-MM-DD : directory containing the post processed "*projection_xxx.bin*" data generated on this date and the reconstructions using this data.

(1) *readme.txt* : contains input raw data info, phantom name, and run date.

(2) *TVcorr.txt* : contains TV corrected WEPL calibration curve coefficients.

(3) *WcalibTemp.txt* : temporary file containing WEPL calibration curve coefficients.

(4) *Wcalib.txt* : contains final WEPL calibration curve coefficients.

(5) *projection_xxx.bin* : preprocessed data files containing tracker coordinates and WEPL data for gantry angle "*xxx*" = {"*001*", "*002*", "*003*", $\cdots$} used as input to image reconstruction.

(6) /Reconstruction : directory containing preprocessed data and reconstructed images generated using the "*projection_xxx.bin*" data along with reference images relevant to the object.

(a) *settings.cfg* : configuration file containing key/value pairs specifying scan/phantom properties (phantom, run date/#/tag(s), etc.) and default reconstruction settings/-parameters.

(b) /YY-MM-DD : directory containing the preprocessed data generated on this date and the reconstructed images generated from this data.

(i) *execution_log.txt* : execution times for various portions of preprocessing and/or reconstruction and total program execution time.

(ii) *FBP.txt* : text image of filtered back projection (FBP) image.

(iii) *FBP.png* : conversion of "*FBP.txt*" to PNG image.

(iv) *FBP_med_filtered.txt* : text image result of applying median filter to the filtered back projection (FBP) image.

(v) *FBP_med_filtered.png* : conversion of "*FBP_avg_filtered.txt*" to PNG image.

(vi) *hull.txt* : text image of selected object hull in 1s/0s.

(vii) *hull.png* : conversion of "*hull.txt*" to PNG image.

(viii) *hull_avg_filtered.txt* : text image result of applying average filter to the hull image.

(ix) *hull_avg_filtered.png* : conversion of "*hull_avg_filtered.txt*" to PNG image.

(x) *settings_log.cfg* : copy of "*settings.cfg*" with any changes made to parameters/options applied at execution, if any.

(xi) *TV_measurements.txt* : total variation (TV) measurements before/after each iteration

(xii) *x_0.txt* : text image of initial iterate.

(xiii) *x_0.png* : conversion of "*x_0.txt*" to PNG image.

(xiv) /Images : directory containing reconstructed images generated using this preprocessed data.

(1) /YY-MM-DD : directory containing the reconstructed images generated on this date using the preprocessed data above.

(a) *x_k.txt* : text image of reconstructed image x^k after k iterations.

(b) *x_k.png* : PNG image of reconstructed image x^k after k iterations.

(c) /Simulated : directory containing data and images generated from simulated scans of the object.

(i) /G_YY-MM-DD : directory containing data and reconstructed images from the GEANT4 simulated scan of the object generated on this date..

(1) /XXXX[_AAA] : directory containing data/images corresponding to the 4-digit run # "*XXXX*", potentially including *"subcategory tag(s)"* of the form "*_AAA*" indicating, e.g., a continuous scan

("*_Cont*"), phantom position/section (inferior ("*_Inf*") or superior ("*_Sup*"), top ("*_Top*") or bottom ("*_Bot*"), etc.).

(a) /Input : directory containing raw data files generated by simulated scan of object for each gantry angle.

(i) *raw_xxx.bin* : binary files containing trigger/tracker/energy detector data from event builder associated with gantry angle "*xxx*" ={"*001*", "*002*", "*003*", ···}.

(b) /Output : directory containing calibration and post processed data generated from analysis of raw data and used as input to image reconstruction.

(i) /YY-MM-DD : directory containing the post processed "*projection_xxx.bin*" data generated on this date and the reconstructions using this data.

(1) *readme.txt* : contains input raw data info, phantom name, and run date.

(2) *TVcorr.txt* : contains TV corrected WEPL calibration curve coefficients.

(3) *WcalibTemp.txt* : temporary file containing WEPL calibration curve coefficients.

(4) *Wcalib.txt* : contains final WEPL calibration curve coefficients.

(5) *projection_xxx.bin* : preprocessed data files containing tracker coordinates and WEPL data for gantry angle "*xxx*" = {"*001*", "*002*", "*003*", ···} used as input to image reconstruction.

(6) /Reconstruction : directory containing preprocessed data and reconstructed images generated using the "*projection_xxx.bin*" data along with reference images relevant to the object.

(a) *settings.cfg* : configuration file containing key/value pairs specifying scan/phantom properties (phantom, run date/#/tag(s), etc.) and default reconstruction settings/-parameters.

(b) /YY-MM-DD : directory containing the preprocessed data generated on this date and the reconstructed images generated from this data.

(i) *execution_log.txt* : execution times for various portions of preprocessing and/or reconstruction and total program execution time.

(ii) *FBP.txt* : text image of filtered back projection (FBP) image.

(iii) *FBP.png* : conversion of "*FBP.txt*" to PNG image.

(iv) *FBP_med_filtered.txt* : text image result of applying median filter to the filtered back projection (FBP) image.

(v) *FBP_med_filtered.png* : conversion of "*FBP_avg_filtered.txt*" to PNG image.

(vi) *hull.txt* : text image of selected object hull in 1s/0s.

(vii) *hull.png* : conversion of "*hull.txt*" to PNG image.

(viii) *hull_avg_filtered.txt* : text image result of applying average filter to the hull image.

(ix) *hull_avg_filtered.png* : conversion of "*hull_avg_filtered.txt*" to PNG image.

(x) *settings_log.cfg* : copy of "*settings.cfg*" with any changes made to parameters/options applied at execution, if any.

(xi) *TV_measurements.txt* : total variation (TV) measurements before/after each iteration

(xii) *x_0.txt* : text image of initial iterate.

(xiii) *x_0.png* : conversion of "*x_0.txt*" to PNG image.

(xiv) /Images : directory containing reconstructed images generated using this preprocessed data.

(1) /YY-MM-DD : directory containing the reconstructed images generated on this date using the preprocessed data above.

(a) *x_k.txt* : text image of reconstructed image x^k after k iterations.

(b) *x_k.png* : PNG image of reconstructed image x^k after k iterations.

(ii) /T_YY-MM-DD : directory containing data and reconstructed images corresponding to all TOPAS simulated scans of the object generated on this date.

(1) /XXXX[_AAA] : directory containing data/images corresponding to the 4-digit run # "*XXXX*", potentially including *"subcategory tag(s)"* of the form "*_AAA*" indicating, e.g., a continuous scan ("*_Cont*"), phantom position/section (inferior ("*_Inf*") or superior ("*_Sup*"), top ("*_Top*") or bottom ("*_Bot*"), etc.).

(a) /Input : directory containing raw data files generated by simulated scan of object for each gantry angle.

(i) *raw_xxx.bin* : binary files containing trigger/tracker/energy detector data from event builder associated with gantry angle "*xxx*" ={"*001*", "*002*", "*003*", $\cdots$}.

(b) /Output : directory containing calibration and post processed data generated from analysis of raw data and used as input to image reconstruction.

(i) /YY-MM-DD : directory containing the post processed "*projection_xxx.bin*" data generated on this date and the reconstructions using this data.

(1) *readme.txt* : contains input raw data info, phantom name, and run date.

(2) *TVcorr.txt* : contains TV corrected WEPL calibration curve coefficients.

(3) *WcalibTemp.txt* : temporary file containing WEPL calibration curve coefficients.

(4) *Wcalib.txt* : contains final WEPL calibration curve coefficients.

(5) *projection_xxx.bin* : preprocessed data files containing tracker coordinates and WEPL data for gantry angle "*xxx*" = {"*001*", "*002*", "*003*", $\cdots$} used as input to image reconstruction.

(6) /Reconstruction : directory containing preprocessed data and reconstructed images generated using the "*projection_xxx.bin*" data along with reference images relevant to the object.

(a) *settings.cfg* : configuration file containing key/value pairs specifying scan/phantom properties (phantom, run date/#/tag(s), etc.) and default reconstruction settings/-parameters.

(b) /YY-MM-DD : directory containing the preprocessed data generated on this date and the reconstructed images generated from this data.

(i) *execution_log.txt* : execution times for various portions of preprocessing and/or reconstruction and total program execution time.

(ii) *FBP.txt* : text image of filtered back projection (FBP) image.

(iii) *FBP.png* : conversion of "*FBP.txt*" to PNG image.

(iv) *FBP_med_filtered.txt* : text image result of applying median filter to the filtered back projection (FBP) image.

(v) *FBP_med_filtered.png* : conversion of "*FBP_avg_filtered.txt*" to PNG image.

(vi) *hull.txt* : text image of selected object hull in 1s/0s.

(vii) *hull.png* : conversion of "*hull.txt*" to PNG image.

(viii) *hull_avg_filtered.txt* : text image result of applying average filter to the hull image.

(ix) *hull_avg_filtered.png* : conversion of "*hull_avg_filtered.txt*" to PNG image.

(x) *settings_log.cfg* : copy of "*settings.cfg*" with any changes made to parameters/options applied at execution, if any.

(xi) *TV_measurements.txt* : total variation (TV) measurements before/after each iteration

(xii) *x_0.txt* : text image of initial iterate.

(xiii) *x_0.png* : conversion of "*x_0.txt*" to PNG image.

(xiv) /Images : directory containing reconstructed images generated using this preprocessed data.

(1) /YY-MM-DD : directory containing the reconstructed images generated on this date using the preprocessed data above.

(a) *x_k.txt* : text image of reconstructed image x^k after k iterations.

(b) *x_k.png* : PNG image of reconstructed image x^k after k iterations.

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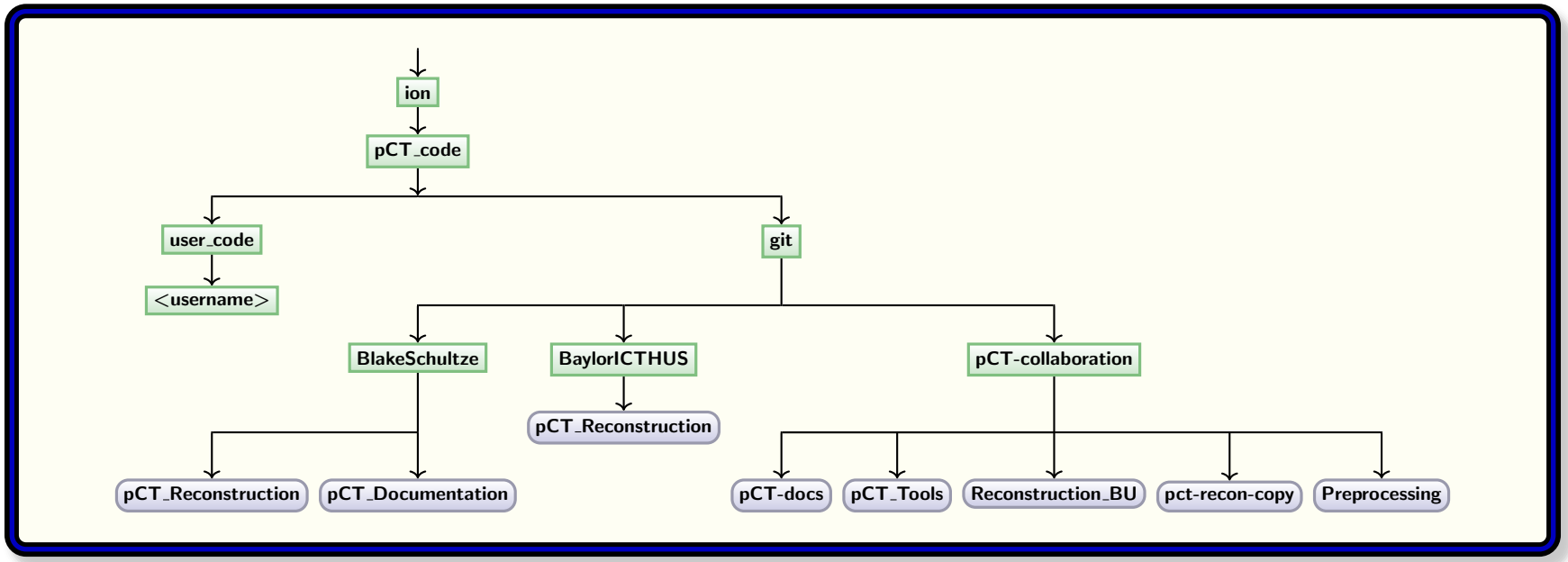
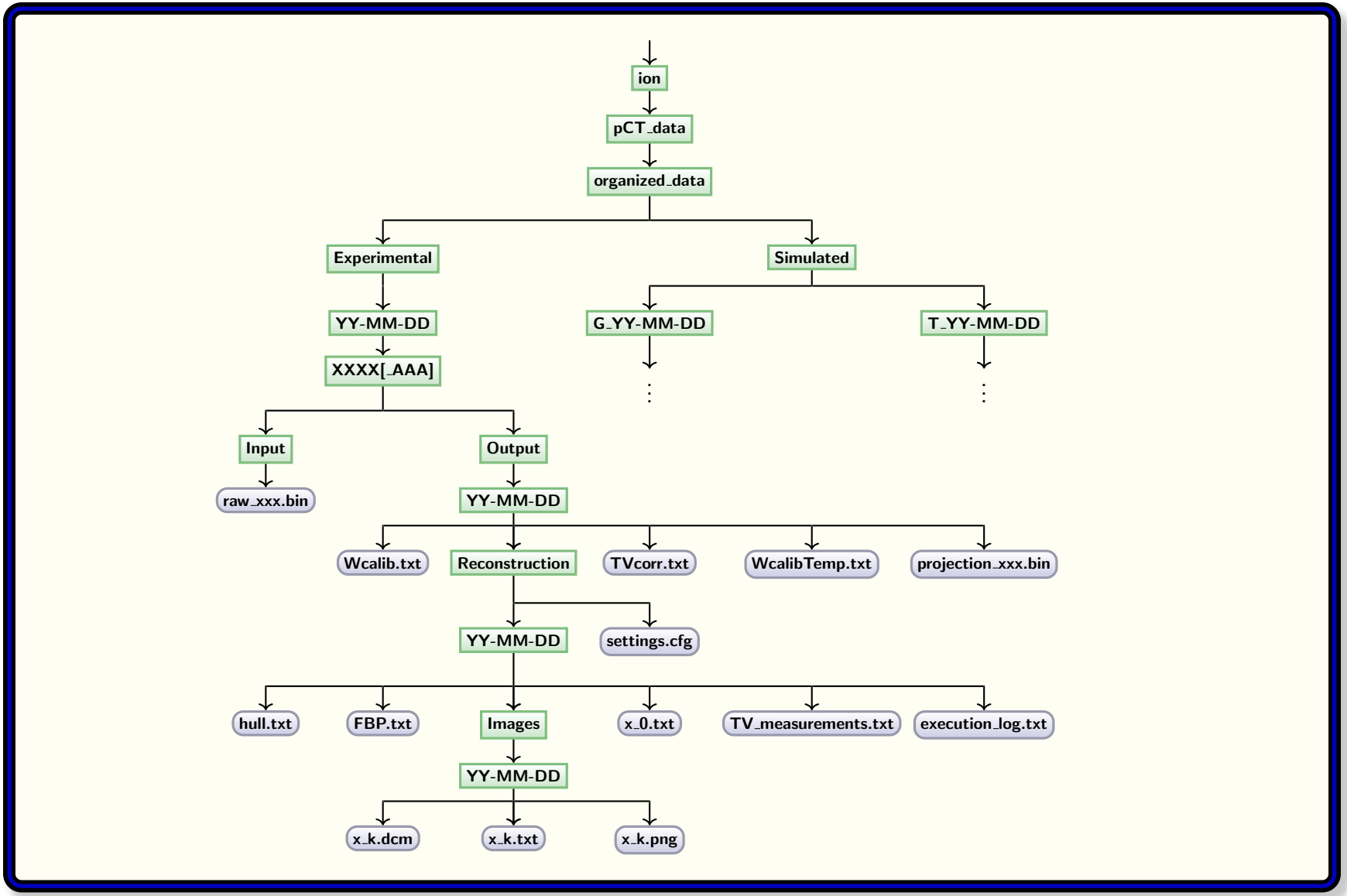
19.1 : pCT_code Hierarchy Diagram

The diagram below shows the hierarchy of /pCT_code directories listed and described in the pCT Code Hierarchy section, including the clones of the most commonly used GitHub accounts/repositories relevant to pCT (described in the GitHub Accounts/Repositories section).



19.2 : organized_data Hierarchy Diagram

The diagram below shows the hierarchy of /organized_data directories. The vertical ellipses (⋮) indicate that the subdirectories below this level of the branch are identical to those below this same level of the branch that shows these subdirectories explicitly.



20.1 : GitHub Accounts/Repositories

GitHub

https://github.com/<*GitHub account*>/<*GitHub repository*>

– below is a description of the GitHub accounts/repositories containing the tools/programs relevant to pCT and documentation for pCT software/hardware, code/data storage and management, collaborator projects and contact information, phantom naming/properties, and other useful pCT information. These have been cloned to Kodiak/Tardis and organized according to the scheme described in Code Organization and shown in the pCT_code Hierarchy Diagram, thereby providing users with easy/immediate access to the source code in these repositories.

(1) /pCT-collaboration : contains repositories for pCT data acquisition, simulation, preprocessing, and reconstruction software and documentation describing the software/hardware, management of code/data, and other information relevant to pCT (e.g. collaborator list, hardware descriptions, phantom properties, etc.).

(a) /pCT_Tools : contains bash functions/scripts and other tools useful for navigating data/code and configuring/running programs on Kodiak and Tardis compute nodes (along with documentation describing them and their purpose/usage) including a default `.bash_profile` which sources `pct_user_script.sh` to configure user sessions for the current host/node and `load_pct_functions.sh` to automatically load the aforementioned bash functions useful during a user terminal session (see *documentation.pdf* for

(b) /pCT-docs : contains documentation on the pCT data/code naming and organizational scheme, collaborator's project involvement and contact info, and phantom properties/manuals/naming (including relevant subcategory tags). The importance and naming of additional documentation from the original /BlakeSchultze/pCT_Documentation repository are currently being evaluated for migration.

(c) /pypct : Python helpers for proton CT

(d) /pct-acquire : Proton CT data acquisition software for the Phase 2 pCT scanner system

(e) /pct-sim : GEANT4 program for simulating scans with the Phase 2 pCT scanner system

(f) /Preprocessing : program for preprocessing raw data to calculate tracker plane coordinates from tracker

chip/channel/strip values and generate calibrated WEPL values from energy detector measurements.

(g) /pct-recon-copy : original Penfold/Hurley pCT reconstruction program now with a Baylor branch configuring the Makefile for Tardis execution and input/output directory execution parameters required for batch script submission of reconstruction job(s) to the GPU execution queue.

(h) /Reconstruction_BU : contains only the current and previous release versions of Baylor's reconstruction program as developed in /BaylorICTHUS/pCT_Reconstruction (no code development is performed here).

(2) /BaylorICTHUS : Baylor's pCT programs, tools, and documentation.

(a) /pCT_Reconstruction : used in developing the release version of Baylor's pCT reconstruction program and containing branches for each of Baylor's pCT developers (Blake, Paniz, Sarah, ...) for independent development relevant to their work. Developments made in a developer branch and proposed for integration in the next release version go through a review and testing process to verify the code and its impact on the full program. Developments passing this verification process are then merged into the release_development branch. When critical developments are merged into the release_development branch, this branch is then merged into the release branch and the resulting code is then pushed to the /pCT-collaboration/Reconstruction_BU repository, as this is the source for pCT users to acquire the current and previous release versions of the program.

(3) /BlakeSchultze : parent directory for all pCT code/data on Kodiak and the Tardis compute nodes

(a) /LaTeX-Packages : provides the package "*my-latex.sty*" which is included in TeX documents to provide access to the definitions of new commands/macros/environments, load the external/3rd-party package dependencies, and configure the typesetting of LaTeX documents as well as providing the collection of LaTeX style (.sty) and other files included in this repository upon which these definitions/configurations are dependent.

(b) /pCT_Documentation : contains an expanded set of pCT documentation files with additional resources not included in the /pCT-collaboration/pCT-docs repository, such as pCT publications and theses/dissertations.

(c) /pCT_Reconstruction : the original repository in which Baylor's pCT reconstruction program was developed, which also contains the experimental development of an alternative program configuration with several automated routines, and is currently being merged into the release version of Baylor's reconstruction program as provided in /BaylorICTHUS/pCT_Reconstruction.

(d) /WED_Analysis : provides tool for determining the water-equivalent depth (WED) for a set of beam-aim point (BAP) coordinates based on reconstructed image RSP values, using the voxel walk algorithm developed as part of the pCT reconstruction program. This algorithm steps from voxel edge to voxel edge

along a trajectory to determine exact voxel intersection coordinates and prevent the missing of small voxel intersections which can occur when taking constant length steps along a path as was done in the original reconstruction program.

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21.1 : reconstruction_data File List

Reconstruction File List

Contents:

Below is a list of optional reconstruction data/image files not written to disk by default and not listed in the Reconstruction Data Hierarchy section.

1. *bin_counts.txt* : linearized bin # for each proton history, where linearized bin # = t_bin + angle_bin * T_BINS + v_bin * T_BINS * ANGULAR_BINS.
2. *coefficient.bin* : file containing the tabulated scattering coefficient values for Σ_1/Σ_2 for $u_2 - u_1/u_1$ values
3. *cos_table.bin* : file containing the tabulated values of cosine function
4. *execution_log.csv* : global execution log containing entries with scan/object information and the settings/parameters used in reconstruction for each reconstructions performed to date, with new row entries added each time the reconstruction program is executed.
5. *FBP.txt* : text image of filtered back projection (FBP) image.
6. *FBP.png* : conversion of "*FBP.txt*" to PNG image.
7. *FBP_med_filtered.txt* : text image result of applying median filter to the filtered back projection (FBP) image.
8. *FBP_med_filtered.png* : conversion of "*FBP_avg_filtered.txt*" to PNG image.
9. *FBP_avg_filtered.txt* : text image result of applying average filter to the filtered back projection (FBP) image.
10. *FBP_avg_filtered.png* : conversion of "*FBP_avg_filtered.txt*" to PNG image.
11. *histories.bin* : binary file specifying entry/exit coordinates/angles, bin number, gantry angle, and hull entry x/y/z voxel # for each history entering hull.
12. *hull_avg_filtered.txt* : text image result of applying average filter to the hull image.

13. *hull_avg_filtered.png* : conversion of "*hull_avg_filtered.txt*" to PNG image.
14. *mean_rel_ut_angle.txt* : mean relative ut angle ($\angle ut_{out} - \angle ut_{in}$) by linearized bin #.
15. *mean_rel_uv_angle.txt* : mean relative uv angle ($\angle uv_{out} - \angle uv_{in}$) by linearized bin #.
16. *mean_WEPL.txt* : mean WEPL value by linearized bin #.
17. *MLP.bin* : binary file with MLP path data for each history entering hull.
18. *MSC_counts.txt* : text image indicating the # of times each voxel was identified as lying outside the object using Modified Space/Silhouette Carving with the xy plane of each slice stacked on each other.
19. *MSC_hull.txt* : text image of object hull in 1s/0s obtained using Modified Space/Silhouette Carving with the xy plane of each slice stacked on each other.
20. *MSC_hull.png* : conversion of "*MSC_hull.txt*" to PNG image.
21. *poly_1_2.bin* : file containing the tabulated MLP polynomial values with coefficients $\{1, 2, 3, 4, 5, 6\}$
22. *poly_2_3.bin* : file containing the tabulated MLP polynomial values with coefficients $\{2, 3, 4, 5, 6, 7\}$
23. *poly_3_4.bin* : file containing the tabulated MLP polynomial values with coefficients $\{3, 4, 5, 6, 7, 8\}$
24. *poly_2_6.bin* : file containing the tabulated MLP polynomial values with coefficients $\{2, 6, 12, 20, 30, 42\}$
25. *poly_3_12.bin* : file containing the tabulated MLP polynomial values with coefficients $\{3, 12, 30, 60, 105, 168\}$
26. *SC_hull.txt* : text image of object hull in 1s/0s obtained using Space/Silhouette Carving with the xy plane of each slice stacked on each other.
27. *SC_hull.png* : conversion of "*SC_hull.txt*" to PNG image.
28. *sinogram.txt* : mean WEPL after statistical cuts with the t_{bin} and angular bin θ_{bin} plane for each vertical bin v_{bin} stacked on each other.
29. *sin_table.bin* : file containing the tabulated values of sine function
30. *SM_counts.txt* : text image indicating the # of times each voxel was identified as lying outside the object using Space/Silhouette Modeling with the xy plane of each slice stacked on each other.
31. *SM_hull.txt* : text image of object hull in 1s/0s obtained using Space/Silhouette Modeling with the xy plane of each slice stacked on each other.

32. *SM_hull.png* : conversion of "*SM_hull.txt*" to PNG image.
33. *stddev_rel_ut_angle.txt* : standard deviation of the relative ut angle ($\angle ut_{out} - \angle ut_{in}$) by linearized bin #.
34. *stddev_rel_uv_angle.txt* : standard deviation of the relative uv angle ($\angle uv_{out} - \angle uv_{in}$) by linearized bin #.
35. *stddev_WEPL.txt* : standard deviation of the WEPL value by linearized bin #.
36. *WEPL.bin* : binary file specifying WEPL value for each history entering hull.

21.2 : Master File List

Master File List

Contents:

Below is a master list of files and their descriptions in alphabetical order.

1. *<Phantom>_XXXX[_AAA]_xxx.dat* : raw experimental data for the object named "*<Phantom>*", from run # "*XXXX[_AAA]*", where "*XXXX*" is a 4 digit # with leading zeros, "*_AAA*" are optional "*subcategory tag(s)*" indicating, e.g., a continuous scan ("*_Cont*"), phantom position/section (inferior ("*_Inf*") or superior ("*_Sup*"), top ("*_Top*") or bottom ("*_Bot*"), etc.), and "*xxx*" is the gantry angle at which the data was acquired.
2. *<Phantom>_XXXX[_AAA]_xxx.dat.root.reco.root.bin* : preprocessed experimental data with tracker coordinates, recovery of missing hits when possible, and calibrated WEPL measurements for the object named "*<Phantom>*", from run # "*XXXX[_AAA]*", where "*XXXX*" is a 4 digit # with leading zeros, "*_AAA*" are optional "*subcategory tag(s)*" indicating, e.g., a continuous scan ("*_Cont*"), phantom position/section (inferior ("*_Inf*") or superior ("*_Sup*"), top ("*_Top*") or bottom ("*_Bot*"), etc.), and "*xxx*" is the gantry angle at which the data was acquired.
3. *bin_counts.txt* : linearized bin # for each proton history, where linearized bin # = t_bin + angle_bin * T_BINS + v_bin * T_BINS * ANGULAR_BINS.
4. *coefficient.bin* : file containing the tabulated scattering coefficient values for Σ_1/Σ_2 for $u_2 - u_1/u_1$ values

5. *cos_table.bin* : file containing the tabulated values of cosine function
6. *execution_log.csv* : global execution log containing entries with scan/object information and the settings/parameters used in reconstruction for each reconstructions performed to date, with new row entries added each time the reconstruction program is executed.
7. *execution_log.txt* : execution times for various portions of preprocessing and/or reconstruction and total program execution time.
8. *FBP.txt* : text image of filtered back projection (FBP) image.
9. *FBP.png* : conversion of "*FBP.txt*" to PNG image.
10. *FBP_med_filtered.txt* : text image result of applying median filter to the filtered back projection (FBP) image.
11. *FBP_med_filtered.png* : conversion of "*FBP_avg_filtered.txt*" to PNG image.
12. *FBP_avg_filtered.txt* : text image result of applying average filter to the filtered back projection (FBP) image.
13. *FBP_avg_filtered.png* : conversion of "*FBP_avg_filtered.txt*" to PNG image.
14. *histories.bin* : sbinary file specifying entry/exit coordinates/angles, bin number, gantry angle, and hull entry x/y/z voxel # for each history entering hull.
15. *hull.txt* : text image of selected object hull in 1s/0s.
16. *hull.png* : conversion of "*hull.txt*" to PNG image.
17. *hull_avg_filtered.txt* : text image result of applying average filter to the hull image.
18. *hull_avg_filtered.png* : conversion of "*hull_avg_filtered.txt*" to PNG image.
19. *mean_rel_ut_angle.txt* : mean relative ut angle ($\angle ut_{out} - \angle ut_{in}$) by linearized bin #.
20. *mean_rel_uv_angle.txt* : mean relative uv angle ($\angle uv_{out} - \angle uv_{in}$) by linearized bin #.
21. *mean_WEPL.txt* : mean WEPL value by linearized bin #.
22. *MLP.bin* : binary file with MLP path data for each history entering hull.
23. *MSC_counts.txt* : text image indicating the # of times each voxel was identified as lying outside the object using Modified Space/Silhouette Carving.
24. *MSC_hull.txt* : text image of object hull in 1s/0s obtained using Modified Space/Silhouette Carving.
25. *MSC_hull.png* : conversion of "*MSC_hull.txt*" to PNG image.

26. *poly_1_2.bin* : file containing the tabulated MLP polynomial values with coefficients $\{1, 2, 3, 4, 5, 6\}$
27. *poly_2_3.bin* : file containing the tabulated MLP polynomial values with coefficients $\{2, 3, 4, 5, 6, 7\}$
28. *poly_3_4.bin* : file containing the tabulated MLP polynomial values with coefficients $\{3, 4, 5, 6, 7, 8\}$
29. *poly_2_6.bin* : file containing the tabulated MLP polynomial values with coefficients $\{2, 6, 12, 20, 30, 42\}$
30. *poly_3_12.bin* : file containing the tabulated MLP polynomial values with coefficients $\{3, 12, 30, 60, 105, 168\}$
31. *projection_xxx.bin* : preprocessed data files containing tracker coordinates and WEPL data for gantry angle "*xxx*" = {"*001*", "*002*", "*003*", $\cdots$} used as input to image reconstruction.
32. *raw_xxx.bin* : binary files containing trigger/tracker/energy detector data from event builder associated with gantry angle *xxx* = {*001*, "*002*", *003*, $\cdots$}.
33. *readme.txt* : contains input raw data info, phantom name, and run date.
34. *settings.cfg* : specifies scan properties such as gantry angle interval, t/v detector size, reconstruction volume dimensions, etc and default settings and parameters to use in reconstructing this data set.
35. *settings_log.cfg* : copy of "*settings.cfg*" with any changes made to parameters/options applied at execution, if any.
36. *SC_hull.txt* : text image of object hull in 1s/0s obtained using Space/Silhouette Carving.
37. *SC_hull.png* : conversion of "*SC_hull.txt*" to PNG image.
38. *sinogram.txt* : mean WEPL after statistical cuts with the t_{bin} and angular bin θ_{bin} plane for each vertical bin v_{bin} stacked on each other.
39. *sin_table.bin* : file containing the tabulated values of sine function
40. *SM_counts.txt* : text image indicating the # of times each voxel was identified as lying outside the object using Space/Silhouette Modeling.
41. *SM_hull.txt* : text image of object hull in 1s/0s obtained using Space/Silhouette Modeling.
42. *SM_hull.png* : conversion of "*SM_hull.txt*" to PNG image.
43. *stddev_rel_ut_angle.txt* : standard deviation of the relative ut angle ($\angle ut_{out} - \angle ut_{in}$) by linearized bin #.
44. *stddev_rel_uv_angle.txt* : standard deviation of the relative uv angle ($\angle uv_{out} - \angle uv_{in}$) by linearized bin #.
45. *stddev_WEPL.txt* : standard deviation of the WEPL value by linearized bin #.

46. *TVcorr.txt* : contains TV corrected WEPL calibration curve coefficients.
47. *TV_measurements.txt* : contains total variation (TV) measurements before/after each iteration
48. *x_0.txt* : text image of initial iterate.
49. *x_0.png* : conversion of "*x_0.txt*" to PNG image.
50. *x_k.txt* : text image of reconstructed image x^k after k iterations.
51. *x_k.png* : PNG image of reconstructed image x^k after k iterations.
52. *Wcalib.txt* : contains final WEPL calibration curve coefficients.
53. *WcalibTemp.txt* : temporary file containing WEPL calibration curve coefficients.
54. *WEPL.bin* : binary file specifying WEPL value for each history entering hull.

Part V

LaTeX Kernel Effects and Package Integration

CHAPTER 22

fncychap test

23.1 fncysec test

List of Symbols

Symbols | F | O

Symbols

$\widetilde{\boldsymbol{m}}$ $(\widetilde{m})$ – symbol m2 ..... 30, 82, 85

$\boldsymbol{m}$ (m) – symb m 30, 82, 85

F

function $(f(\cdot))$ – This is a function 30, 82, 85

O

ohm (Ω) – unit of electrical resistance 30, 82, 85

List of Acronyms

C | F | L | O

C

CFRIP – Collaborative Faculty Research Investment Program ..... 30, 82, 85, *see* Collaborative Faculty Research Investment Program

F

FPS – Frame per Second 30, 82, 85

FPSs – Frame per Seconds 30, 82, 85

L

LVM – Logical Volume Manager 30, 82, 85

O

OWD – One-Way Delay ..... 30, 82, 85, *see* One-Way Delay

List of Abbreviations

etc Et cetera 30, 87, 90, 109

MFA My fancy abbreviation 30, 87, 90, 109

Glossary

C | L | N | O | P | R

C

Collaborative Faculty Research Investment Program is a joint Baylor University, Baylor Scott & White Health, and Baylor College of Medicine program providing seed funding for inter-institutional/disciplinary research projects ..... 30, 82, 85, *see* CFRIP

computer is a programmable machine that receives input, stores and manipulates data, and provides output in a useful format 99

L

Linux is a generic term referring to the family of Unix-like computer operating systems that use the Linux kernel 30, 82, 85

N

naïve is a French loanword (adjective, form of naïf) indicating having or showing a lack of experience, understanding or sophistication .. 99

O

One-Way Delay The time a packet uses through a network from one host to another ..... 30, 82, 85, *see* OWD

P

π ratio of circumference of circle to its diameter 30, 82, 85

R

real number ($\mathbb{R}$) include both rational numbers, such as 42 and $\frac{-23}{129}$, and irrational numbers, such as π and the 30, 82, 85

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