

# Interactive Scientific Programming Languages

Reference Card — mxn, April 15, 2016, 09:28

<i>Start</i>	Python	R	IDL	Matlab/Octave
Start session	ipython -pylab	RStudio	idl	octave -q
Run code from file	execfile('file.py') or run file.py	source('file.R')	file.pro or .run file.pro	file
Command history	hist -n	history()	help,/rec	history
Save command history		savehistory(file=..)	journal,'file'	diary on and diary off
End session	Ctrl-D or sys.exit()	q()	exit or Ctrl-D	exit or quit
Install packages	pip install ..	install.package()		
Show/Set working path	sys. ..	getwd() / setwd(..)	cd,...,current=curr	
Comment sign	#	#	;	
<i>Help</i>	Python	R	IDL	Matlab/Octave
Interactive	help()	help.start()	?	doc
Help on function f	help(f) or ?f or ??f	help(f) or ?f	?f	help f
Demonstration examples		demo() or example(plot)	demo	
Search more help		help.search('plot') or apropos('plot')		lookfor plot
Locate function	help(plot)	find(plot)		which plot
List methods	dir()	methods(plot)		
Others		str()		
Data Summary		describe(), summary()		
<i>Syntax</i>	Python	R	IDL	Matlab/Octave
Assignment	a=1; b=1	a<-1; b<-2	a=1 & b=2	a=1; b=2;
Procedure				
Function				
Return value	return x	x (last statement)	return, x	as assigned
Object Method				
Operator Precedence	func(); x[ind:ind]; x[ind]; x.attr; **, *,/,%; +,-; <,>,<=,>=,!','=', in,not in; not,and,or			
Terminal Output	print(..)	print()	print, ..	
Terminal Input				
In place: $a=a+b$	a+=b		a+=b	a+=b
In place ops.			+= *= /= #= ##= &&= ..	
<i>Variables/Types</i>	Python	R	IDL	Matlab/Octave
Basic types	int, long, float, complex, bool, str, tuple, list, dict	character, numeric, integer, complex, logical	int, long, float, complex, string, double, byte, ..	
Conversion	int(), float()	as.list, ..	fix(), float(), ..	
Type Checks		is.na(x)		
Not a number	nan	NaN, NA	!values.f_nan	NaN
Infinity	inf, plus_inf		!values.f_infinity	Inf
Complex number 2+i	2+1j	2+1i	complex(2,1)	2+i
Real/Imaginary	np.real(z), z.real, z.imag	Re(z), Im(z)	real_part(z), imagi- nary(z)	real(z), imag(z)
Abs/Argument	abs(z)	abs(z), Arg(z)	abs(z), atan(z,/ph)	abs(z), arg(z)
Complex conjugate	np.conj(z)	Conj(z)	conj(z)	conj(z)

<b>Math</b>	<b>Python</b>	<b>R</b>	<b>IDL</b>	<b>Matlab/Octave</b>
Basic	+ - * / or //	+ - * / or %/%	+ - * /	+ - * / or .* ./
Power $a^b$	a**b	a^b	a^b	a.^b
Modulo	np.mod(a,b)	a%b	a mod b	rem(a,b)
Factorial $a!$	m.factorial(a)	factorial(a)	factorial(a)	
Round	np.round(), np.ceil(), np.floor()	round(), ceil(), floor()	round(), ceil(), floor()	round(), ceil(), floor()
Round towards zero	np.fix()		fix()	fix()
Trigonometry	sin(), cos(), tan(),	asin() or arcsin(), acos() or arccos(), atan()	sinh(), cosh(), tanh()	or arctan() or atan2()
Hyperbolic				
Others	np.sqrt(), np.log(), np.exp()	sqrt(), log(), exp()	sqrt(), alog(), exp()	sqrt(), log(), exp()
Constants	m.pi, m.e	pi, exp(1)	!pi, exp(1)	pi, exp(1)
<b>Relational</b>				
Basic	== < > <= >= !=	== < > <= >= !=	eq lt gt le ge ne	== < > <= >= ~=
<b>Logical</b>				
Single-elem	and or	&&	&&	&&
Element-wise	and or	&	and or	&
XOR		xor(a,b)	a xor b	xor(a,b)
NOT	not a	!a	~a	~a !a
True if any nonzero				any(a)
True if all nonzero				all(a)

<b>Vectors and Matrices</b>	<b>Python</b>	<b>R</b>	<b>IDL</b>	<b>Matlab/Octave</b>
Vector 1,3,-4,10	np.array([1,3,-4,10])	c(1,3,-4,10)	[1,3,-4,10]	[1; 3; -4; 10]
Sequence 1,2,...,10	range(1,11), np.arange(1,11)	1:10, seq(1,10)	indgen(10)+1	1:10
1,4,7,10	np.arange(1,11,3)	seq(1,10,3)	indgen(4)*3+1	1:3:10
Linearly spaced	np.linspace(1,10,7)	seq(1,10,len=7)		linspace(1,10,7)
Zeros $\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$	np.zeros((2,4))	matrix(0,2,4)	fltarr(4,2)	zeros(2,4)
Ones $\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{bmatrix}$	np.ones((2,4))	matrix(1,2,4)	fltarr(4,2)+1	ones(2,4)
Identity matrix	np.identity(3)	diag(3)	identity(3)	eye(3)
Diagonal matrix	np.diag([3,4,5])	diag(c(3,4,5))	diag_matrix([3,4,5])	diag([3 4 5])
Reverse	a[::-1]	rev(a)	reverse(a)	reverse(a)
Transpose	a.T	t(a)	transpose(a)	a.'
Conjugate transpose	a.T.conj()	Conj(t(a))	conj(transpose(a))	a'
Flatten to 1D	np.ravel(a)		a[*]	
Flatten by rows	a.flatten()	as.vector(t(a))		a'(:)
Flatten by columns	a.flatten(1)	as.vector(a)	(transpose(a))[*]	a(:)
Flatten upper triang.		a[row(a)<=col(a)]		vech(a)
Reshape by rows	a.reshape(2,-1) or a.setshape(2,3)	matrix(a,nrow=3, byrow=T)	reform(a,[2,3])	reshape(a,3,2)'
Reshape by columns	a.reshape(-1,2).T	matrix(a,nrow=2)	reform(transpose(a),[2,3])	reshape(a,2,3)
Flip left-right (mirror horiz)	np.fliplr(a) or a[:,::-1]	a[,4:1]	reverse(a)	fliplr(a)
Flip up-down (mirror vert)	np.flipud(a) or a[::-1,]	a[3:1,]	reverse(a,2)	flipud(a)
Rotate 90 deg	np.rot90(a)		rotate(a,1)	rot90(a)
Repeat matrix	np.kron(np.ones((2,3)),a)	kron(matrix(1,2,3),a)		repmat(a,2,3)
Upper/lower triangular	np.triu(), np.tril()	a[lower.tri(a)], a[upper.tri(a)]		triu(), tril()
Assign to all	a.fill(3), a[:]=3		a[*]=3	a(:)=3
Concatenate	np.concatenate((a,b))	c(a,b)	[a,b]	a b
Repeat [1,2,1,2,1,2]	np.concatenate((a,a,a))	rep(a,imes=3)	[a,a,a], repli- cate(a,3)	[a a a]
Repeat [1,1,1,2,2,2]	np.repeat(a,3)	rep(a,each=3)		
Max/Min	np.max(a), np.min(a)	max(a), min(a)	max(a), min(a)	max(a), min(a)
Max/Min position	np.argmax(a)	which.max(a)	v = max(a,pos=i)	[v,i] = max(a)

Continued on the next page...

<i>Vectors and Matrices</i>	Python	R	IDL	Matlab/Octave
Sum (over 1th dim)	np.sum(a,axis=0)	colSum(a)	total(a,1)	sum(a)
Sum (all elems)	np.sum(a)	sum(a)	total(a)	sum(sum(a))
Cumulative sum	np.cumsum(a)	cumsum(a)	total(a,/cum)	cumsum(a)
Dimensions	a.shape	dim(a)	size(a)	size(a)
Specific dimensions	a.ndim, a.nbytes, len(a)	ncol(a), ob- ject.size(a)	n.elements(a)	length(a), ndims(a)

<i>Matrices</i>	Python	R	IDL	Matlab/Octave
Input $\begin{bmatrix} 2 & 3 \\ 4 & 4 \end{bmatrix}$	np.array([[2,3], [4,5]])	array(c(2,3,4,5), c(2,2))	[[2,3],[4,5]]	[2 3; 4 5]
Bind rows	np.vstack((a,b))	rbind(a,b)	[[a],[b]]	[a; b]
Bind columns	np.hstack((a,b))	cbind(a,b)	[a,b]	[a, b]
Bind slices(3d)	np.dstack((a,b))		[[[a]],[[b]]]	
Create single vector	np.concatenate(a,b, axis=None)		[a*],b[*]]	[a(:),b(:)]
Elementwise operations	* / + -	* / + -	* / + -	.* ./
Matrix multiplication	matrixmultiply(a,b)	a%*%b	a#b a##b	a*b
Cross product				
Kronecker product	np.kron(a,b)	kronecker(a,b)		kron(a,b)
Solve linear equations	linalg.solve(a,b)	solve(a,b)	cramer(a,b)	a\b

<i>Indexing</i>	Python	R	IDL	Matlab/Octave
First row	a[0,]	a[1,]	a[:,0]	a(1,:)
Element 2,3 (row, col)	a[1,2]	a[2,3]	a[2,1]	a(2,3)
Array indices			a[[0,3],[0,2]]	a([1 3],[1 4])
Selection	a[2:]	a[-1]	a[1:*]	a(2:end)
Last element	a[-1]		a[n_elements(a)-1]	a(end)
Last 3 rows	a[-3:,:]		a[:,n_elements(a)- 3:*]	a(end-2:end,:)
Every k-th row	a[:,k,:]		a[ind,*]	a(1:2:end,:)
k-th in last dim	a[... ,k]			
All except row 2, col 3		a[-2,-3]		
Diagonal elems	a.diagonal()		diag_matrix(a)	
Clipping	(a>90).choose(a,90) a.clip(min=2,max=90)	a[a>90]<-90	a<90 2>a<90	a(a>90)=90

Mathematical indexing: row-number  $\times$  column-number:  $M_{3 \times 4} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \end{bmatrix}$

<i>Sorting</i>	Python	R	IDL	Matlab/Octave
Sorted values	np.sort(a)	sort(a)	a[sort(a)]	sort(a)
Sorted indices	np.argsort(a)	order(a)	sort(a)	

<i>Linear Algebra</i>	Python	R	IDL	Matlab/Octave
Element-wise multipl.	a*b	a*b	a*b	a.*b
Scalar product $\mathbf{a} \cdot \mathbf{b}$	np.dot(a,b)		transpose(a)#b	dot(a,b)
Cross product $\mathbf{a} \times \mathbf{b}$	np.dot(a,b)		crossp(a,b)	

<i>Find</i>	Python	R	IDL	Matlab/Octave
Nonzero indices	np.nonzero(a)[0] or np.where(a!=0)[0]	which(a!=0,arr.ind=T)	where(a ne 0)	[i j]=find(a)
Return values	a.compress((a>5).flat)	which(a>5)	a[where(a gt 5)]	find(a>5)

<i>Random Numbers</i>	Python	R	IDL	Matlab/Octave
Uniform	np.random.rand()	runif()	randomu()	rand()
Normal	np.random.randn()	rnorm()	randomn()	randn()

## Python

1. concatenate at 1th, 2nd, 3rd dimensions: `np.hstack((a,b))`, `np.vstack((a,b))`, `np.dstack((a,b))`
2. stats: `scipy.stats.binned_statistic` - moving/rolling stats
3. mutable/non-mutable objects: assignment with copy (deepcopy)
4. Bitwise operations: `<<`, `>>`, `&`, `|`, `~`, `^`
5. Functions:
  - `bin(N)` - number to binary (base 2) digits string
  - `ord(C)` - integer code of character (unicode or ascii)
  - `chr(N)` - unicode code number to character string
  - `hex(N)` - number to hexadecimal (base 16) digits string
  - `oct(N)` - number to octal (base 8) digits string
  - `int(S,n)` - base-n digits string to number (e.g. `int('0011',2)`)
6. Numpy
  - For multidimensional data, use `np.array` (not `np.matrix`); and then use `.dot()`, `.conj()`, and `.T` methods and attributes.
  - Slicing doesn't return a new array, but a view of the original. That is, changing `b=a[:,1]` with `b[0]=x` will change `a` as well.
  - C-like index order: `M[i,j]`, where `j` changes fastest → `M[0,:]` is printed first, as row, `M[1,:]` is printed next, etc.
  - Selecting a dimension in array will always reduce the rank, leading e.g. from 2-d to 1-d (or rank) matrix. Transpose doesn't do anything on 1-d array.
  - Array can treat rank-1 arrays as either row or column vectors. For example, `dot(A,v)` treats `v` as a column vector, while `dot(v,A)` treats `v` as a row vector.  
The usual mathematical column vector has shape `(n,1)`. To generate, use e.g.: `c_[x]` or `x.reshape((n,1))` or `x[:,newaxis]`.
  - Fast array creation: `r_[:10]` or `r_[:10.]` or `r_[:10:2]`. Both, `r_[]` and `c_[]` actually create arrays by stacking numbers along a row or a column, and *allow* using the `".."` range slicing operator.
  - Submatrix indexing possible, e.g. with `ix_[(ind,ind)]` form.
  - Linear indexing is not straightforward. First, reshape to a linear sequence, then perform the operations, and then reshape to original size.
  - For array operations along one dimension, use the `axis=` keyword. It starts with 0: `axis=0` for operating on each column, `axis=1` for operating on each row.
  - *Indexing* keyword (e.g. `meshgrid`): `'ij'` = matrix, `'xy'` = cartesian (default). Ideally, use `indexing='ij'` explicitly:  
`A=meshgrid(:M,:N,:P) => A.shape==(N,M,P)`; `meshgrid(:M,:N,:P,indexing='ij') => A.shape==(M,N,P)`
  - Attributes: `ndim`, `shape`, `size`, `dtype`, `itemsizes`, `T`.
  - Creation functions: `array()`, `zeros()`, `ones()`, `eye()`, `arange()`, `linspace()`, `logspace()`, `empty()`, `random.random()`, `copy()`, `identity()`, `mgrid()`, `ogrid()`, `r()` (they usually take tuples for shape).
  - Shape-changing methods: `reshape()`, `ravel()`, `transpose()`, `T`, `resize()`. If a -1 is given in a reshaping operation, the other dimensions are automatically calculated! Others: `atleast_2d()`, `mat()`, `newaxis`.
  - Concatenating: `vstack`, `hstack`, `column_stack`, `row_stack`, `concatenate`.
  - Questions: `all`, `any`, `nonzero`, `where`.
  - Ordering: `argmax`, `argmin`, `argsort`, `max`, `min`, `ptp`, `searchsorted`, `sort`.
  - Operations: `choose`, `compress`, `cumprod`, `cumsum`, `inner`, `fill`, `imag`, `real`, `prod`, `put`, `putmask`, `sum`.
  - Statistics: `cov`, `mean`, `std`, `var`.
  - Linear algebra: `dot`, `cross`, `outer`, `svd`, `vdot`.
  - Others: `histogram()` (similar to IDL)
  - More on fancy indexing and more tricks see/click: [NumPy Tutorial](#) or [NumPy for Matlab Users](#).
7. PyLab / Matplotlib
  - `figsize(x,y)` e.g. `figsize(13,4)`
  - `subplot(yxn)` e.g. `subplot(121)`
8. My conventions:
  - Multi-dimensional data: `[az, rg, pol-channels]`, if channels should be closer together (for block processing along azimuth).

## R

1. loop functions: `map`, `apply`, `sapply`, ..
2. modules: `?modname`, `install.packages`, `library(psych)`
3. info on data set: `str(data)`, `summary(data)`, `head(data)`, `psych.describe(data)`
4. accessing list elements: use double square brackets! e.g. `L[[1]]` (using single brackets will give you back a list again)
5. `smoothScatter(x,y)` – great function!!!! 2-d histogram with densities!
6. `plot(x,y,col=rgb(0,0,0.2),pch=19)` – if many points, adding transparency helps to see where there more and where less points!

## Additional Notes

1. Lexical scope: Python, R — Dynamic scope: IDL, Matlab.
2. Array/matrix indexing:
  - Zero-based: Python, IDL, C/C++
  - One-based: R, Matlab
  - Column-major format (data in memory column-by-column), which is the standard mathematical matrix notation: Python, C/C++. This *C-like* index order changes the last axis index fastest.  
The fastest-changing axis/dimension is read/written/printed to screen first, therefore, a print command in column-major format will print first `a[0,:]` on first line, then `a[1,:]` on second line, etc. If characterizing indices with `i,j` as in `a[i,j]`, then for the print, `x=j`, `y=i`.

$$\begin{bmatrix} a_{0,0} & a_{0,1} & a_{0,2} \\ a_{1,0} & a_{1,1} & a_{1,2} \end{bmatrix} \quad (1)$$

- Row-major format (row-by-row, useful in image processing): IDL, Fortran. This *Fortran-like* index order changes the first axis index fastest.

$$\begin{bmatrix} a_{0,0} & a_{1,0} \\ a_{0,1} & a_{1,1} \end{bmatrix} \quad (2)$$

3. Python, Matlab, R case sensitive, while IDL is case insensitive.