Computer Programming with MATLAB

Lesson 7: Data Types

by

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The Limitation of Computers

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- Real numbers in mathematics:
  - Can be infinitely large
  - Have infinitely fine resolution
- Computers: Finite memory
  - Upper limit on the largest number that can be represented
  - Lower limit on the absolute value of any non-zero number
- The set of values that can be represented by a MATLAB variable is finite.

Data Types

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- MATLAB: many different data types
- A data type is defined by:
  - Set of values
  - Set of operations that can be performed on those values
- MATLAB:
  - All elements of a given array must be of the same type
  - Elementary type
- Type of a MATLAB array is defined by
  - Number of dimensions
  - Size in each dimension
  - Elementary type

Numerical Types

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- double
  - Default type in MATLAB
  - Floating point representation
    - Example: $12.34 = 1234 * 10^{-2}$
    - Mantissa and exponent
  - 64 bits (8 bytes)
- single
  - 32-bit floating point
- Integer types
  - Signed, unsigned
  - 8-, 16-, 32-, 64-bit long

Range of Values

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DATA TYPE	RANGE OF VALUES
`int8`	-2^7 to 2^7-1
`int16`	-2^{15} to $2^{15}-1$
`int32`	-2^{31} to $2^{31}-1$
`int64`	-2^{63} to $2^{63}-1$
`uint8`	0 to 2^8-1
`uint16`	0 to $2^{16}-1$
`uint32`	0 to $2^{32}-1$
`uint64`	0 to $2^{64}-1$
`single`	$-3.4\text{x}10^{38}$ to $3.4\text{x}10^{38}$, `Inf`, `NaN`
`double`	$-1.79\text{x}10^{308}$ to $1.79\text{x}10^{308}$, `Inf`, `NaN`

Range of Values

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DATA TYPE	RANGE OF VALUES
int8	-2^7 to 2^7-1
int16	-2^{15} to $2^{15}-1$
int32	-2^{31} to $2^{31}-1$
int64	-2^{63} to $2^{63}-1$
uint8	0 to 2^8-1
uint16	0 to $2^{16}-1$
uint32	0 to $2^{32}-1$
uint64	0 to $2^{64}-1$
single	$-3.4\text{x}10^{38}$ to $3.4\text{x}10^{38}$, `Inf`, `NaN`
double	$-1.79\text{x}10^{308}$ to $1.79\text{x}10^{308}$, `Inf`, `NaN`

`Inf`:
"Infinity"

`NaN`:
"Not-a-number"

Useful functions

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- Type check:
  - **`class`**
  - **`isa`**

    `>> isa(x,'double')`
- Range check:
  - **`intmax`**, **`intmin`**
  - **`realmax`**, **`realmin`**

    `>> intmax('uint32')`
- Conversion:
  - Name of function = name of desired data type
  - **`int8(x)`**, **`uint32(x)`**, **`double(x)`**, etc.

Operators

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- Arithmetic operators
  - Operands of the same data type: No problem
  - Different data types:
    - “mixed-mode arithmetic”
    - Many rules and restrictions
- Relational operators
  - Different data types are always allowed
  - Result is always of logical type

Strings

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- Text: string
- We have used them already:
  - Argument to **`fprintf`** and other functions
- String: vector of char-s
- Numerical type
  - Uses an encoding scheme
  - Each character is represented by a number
  - ASCII scheme

ASCII code

- American Standard Code for Information Interchange
- Developed in the1960's
- 7 bits, 128 characters:
  - Latin alphabet
  - Digits
  - Punctuation
  - Special characters
- Newer schemes with far more characters
- ASCII is a subset of them

(nul)	0	(sp)	32	@	64	`	96
(soh)	1	!	33	A	65	a	97
(stx)	2	"	34	B	66	b	98
(etx)	3	#	35	C	67	c	99
(eot)	4	$	36	D	68	d	100
(enq)	5	%	37	E	69	e	101
(ack)	6	&	38	F	70	f	102
(bel)	7	'	39	G	71	g	103
(bs)	8	(	40	H	72	h	104
(ht)	9	)	41	I	73	i	105
(nl)	10	*	42	J	74	j	106
(vt)	11	+	43	K	75	k	107
(np)	12	,	44	L	76	l	108
(cr)	13	-	45	M	77	m	109
(so)	14	.	46	N	78	n	110
(si)	15	/	47	O	79	o	111
(dle)	16	0	48	P	80	p	112
(dc1)	17	1	49	Q	81	q	113
(dc2)	18	2	50	R	82	r	114
(dc3)	19	3	51	S	83	s	115
(dc4)	20	4	52	T	84	t	116
(nak)	21	5	53	U	85	u	117
(syn)	22	6	54	V	86	v	118
(etb)	23	7	55	W	87	w	119
(can)	24	8	56	X	88	x	120
(em)	25	9	57	Y	89	y	121
(sub)	26	:	58	Z	90	z	122
(esc)	27	;	59	[	91	{	123
(fs)	28	<	60	\	92	|	124
(gs)	29	=	61	]	93	}	125
(rs)	30	>	62	^	94	~	126
(us)	31	?	63	_	95	(del)	127

Exercise

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- Print out the visible characters of the ASCII table:

```
function char_codes
for ii = 33:126
    fprintf('%s',char(ii));
end
fprintf('\n');
```

String functions

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FUNCTION	DESCRIPTION
`char`	converts type to char
`findstr`	finds the positions of a substring in a string
`ischar`	returns 1 if argument is a character array and 0 otherwise
`isletter`	finds letters in string
`isspace`	finds spaces, newlines, and tabs in string
`isstrprop`	finds characters of specified type in string
`num2str`	converts number to string
`length`	determines the number of letters in string
`lower`	converts string to lower case
`sprintf`	writes formatted data to string (compare with fprintf)
`strcmp`	compares strings
`strcmpi`	like strcmp but independent of case
`strmatch`	search array for rows that begin with specified string
`strncmp`	like strcmp but compares only first n characters
`strncmpi`	like strncmp but independent of case
`str2num`	converts string to number
`upper`	converts string to upper case

Structs

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- An array must be homogeneous:
  - It cannot contain elements of multiple types.
- A struct can be heterogeneous:
  - It can contain multiple types.
- A struct is different from an array:
  - fields, not elements
  - field names, not indices
  - Fields in the same struct can have different types.
- Versatility inside:
  - A field of a struct can contain another struct.

Structs in action

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```
>> r.ssn = 12345678
r =
       ssn: 12345678
>> class(r)
ans =
       struct
>> class(r.ssn)
ans =
       double
>> r.name = 'Homer Simpson'
r =
       ssn: 12345678
       name: 'Homer Simpson'
>> r.address.street = '742 Evergreen Terrace'
r =
       ssn: 12345678
       name: 'Homer Simpson'
       address: [1x1 struct]
```

Structs

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  - It cannot contain elements of multiple types.
- A struct can be heterogeneous:
  - It can contain multiple types.
- A struct is different from an array:
  - fields, not elements
  - field names, not indices
  - Fields in the same struct can have different types.
- Versatility inside:
  - A field of a struct can contain another struct.
  - **Structs can hold arrays, and arrays can hold structs.**

Struct functions

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FUNCTION	DESCRIPTION
`getfield`	returns the value of a field whose name is specified by a string
`isfield`	true if a struct has a field whose name is specified by a string
`isstruct`	returns true if argument is of type struct
`orderfields`	changes the order of the fields in a struct
`rmfield`	removes from a struct a field whose name is specified by a string
`setfield`	assigns a value to a field whose name is specified by a string -or- if the field is not present, adds it and assigns it the value
`struct`	create a struct with fields whose name are specified by strings

Pointers

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- How to store a page of text?
  - Each line should be a separate string
  - Cannot use an array of chars:
    - Each line would have to have the same length
  - A vector of objects with each referring to one line
- Pointer
  - Each variable (scalar, vector, array, etc.) is stored in the computer memory.
  - Each memory location has a unique address.
  - A pointer is a variable that stores an address.
  - MATLAB calls a pointer a “cell”.

Cells

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- MATLAB has a restrictive pointer model
  - Strict rules on what can be done with cells
  - Harder to make mistakes
- But it is a powerful way to store heterogeneous data
  - Cell arrays
  - Used more frequently than structs
- New syntax:
  - To access the data a cell points to, use: { }

Cell array example

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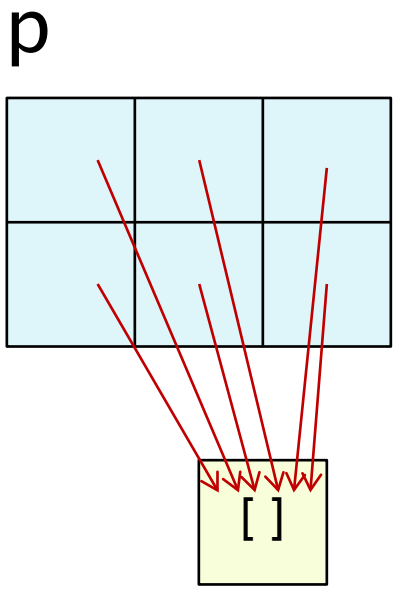
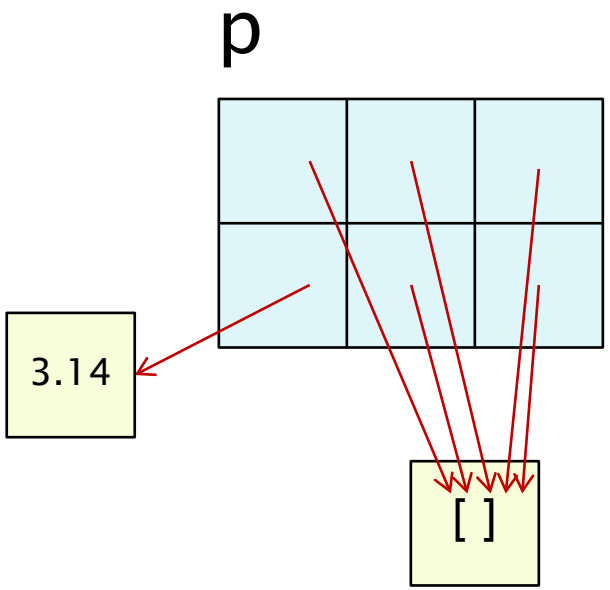
```
>> p = cell(2,3)
p =
    []      []      []
    []      []      []
>>
```



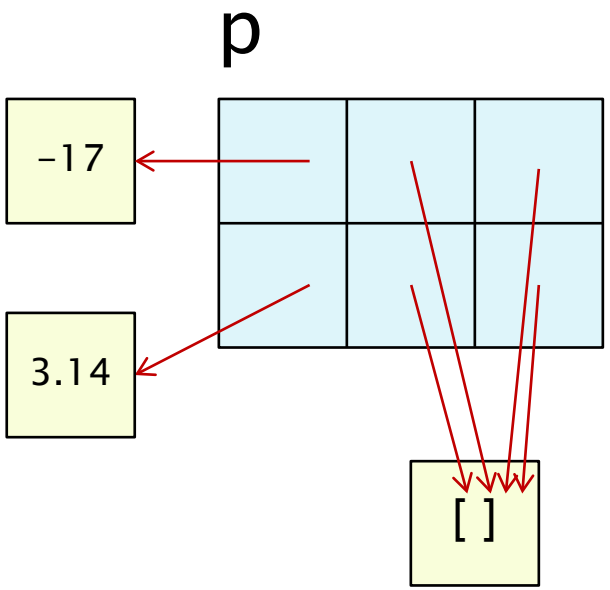
Cell array example

```
>> p = cell(2,3)
p =
    []      []      []
    []      []      []
>> p{2,1} = pi
p =
    []      []      []
    [3.14]  []      []
>>
```



Cell array example

```
>> p = cell(2,3)
p =
    []       []       []
    []       []       []
>> p{2,1} = pi
p =
    []       []       []
    [3.14]   []       []
>> p{1,1} = int8(-17)
p =
     [-17]   []       []
    [3.14]   []       []
>>
```



Cell array example

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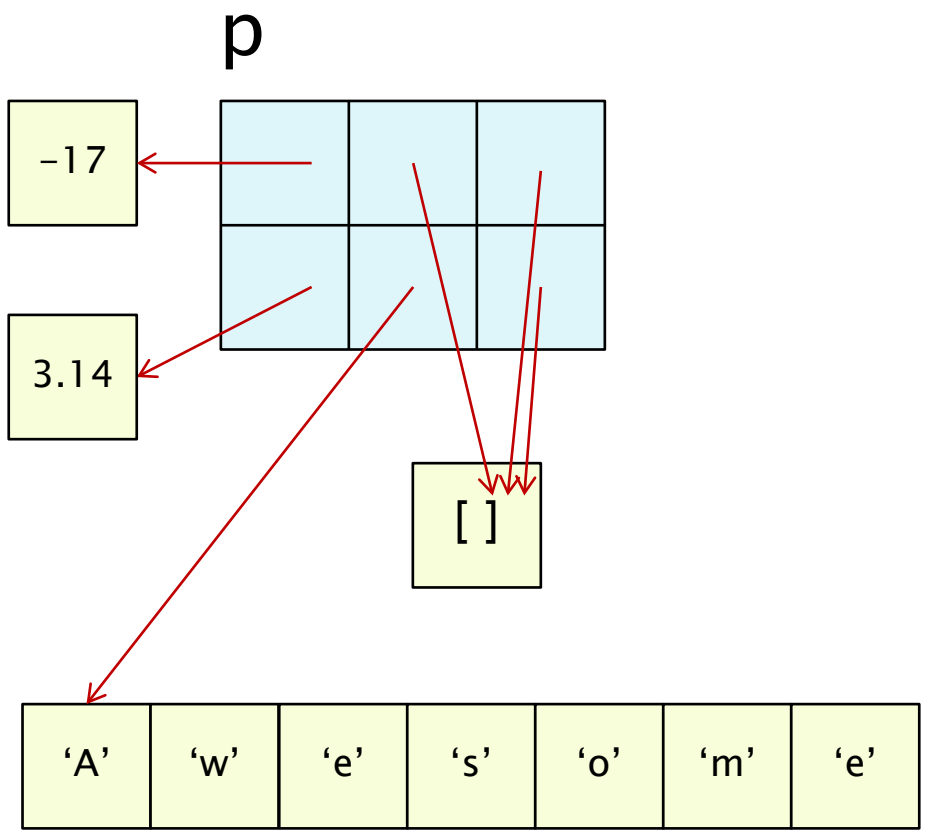
```
>> p = cell(2,3)
p =
    []       []       []
    []       []       []
>> p{2,1} = pi
p =
    []       []       []
    [3.14]   []       []
>> p{1,1} = -17
p =
    [-17]    []       []
    [3.14]   []       []
>> p{2,2} = 'Awesome'
P =
    [-17]    []       []
    [3.14]  'Awesome'  []
```



Cell array example

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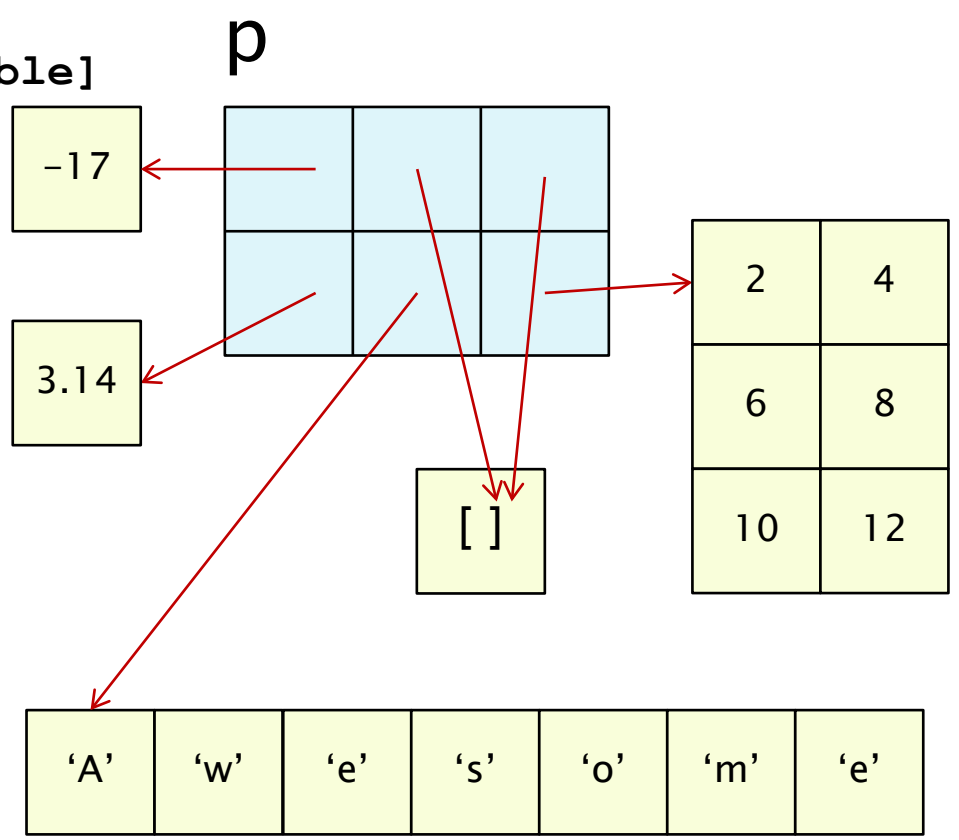
```
>> p{2,3} = [2 4; 6 8; 10 12]
P =
    [-17]   []        []
   [3.14]  'Awesome'  [3x2 double]

>>
```



Cell array example

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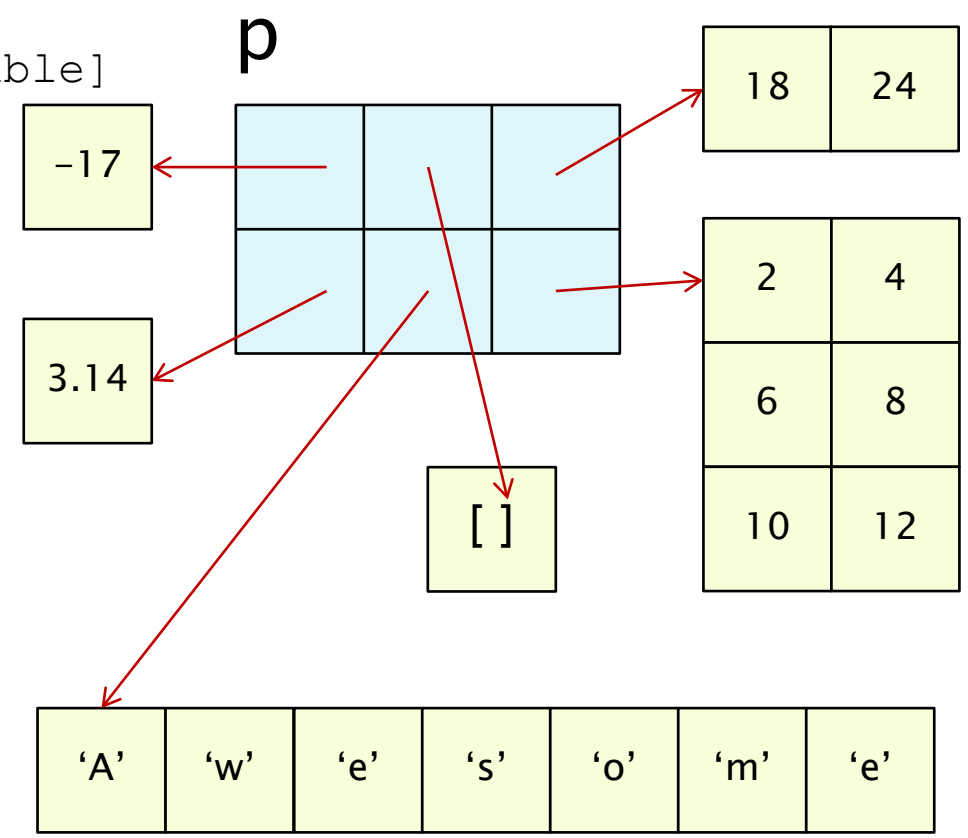
```
>> p{2,3} = [2 4; 6 8; 10 12]
P =
    [-17]   []       []
   [3.14] 'Awesome'[3x2 double]

>> p{1,3} = sum(p{2,3});
>>
```



Cell array example

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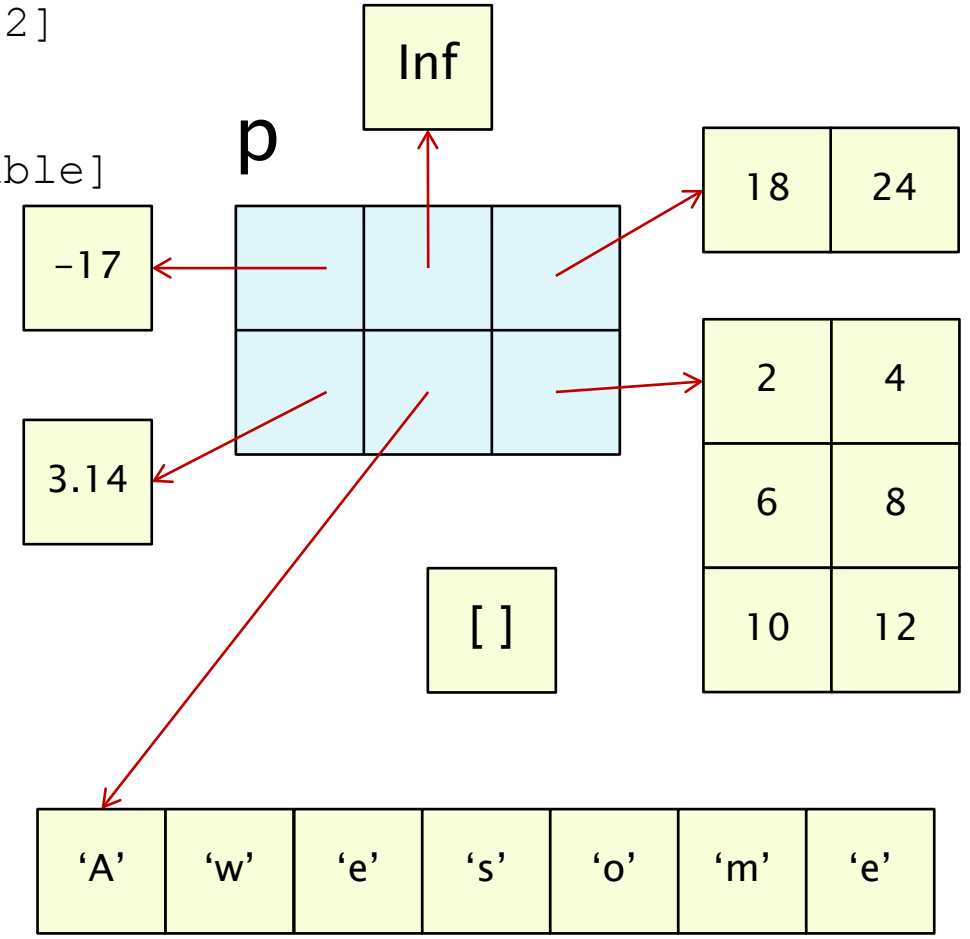
```
>> p{2,3} = [2 4; 6 8; 10 12]
P =
    [-17]   []       []
   [3.14] 'Awesome'[3x2 double]

>> p{1,3} = sum(p{2,3});
>> P{1,2} = 1/0;
>>
```



Cell array example

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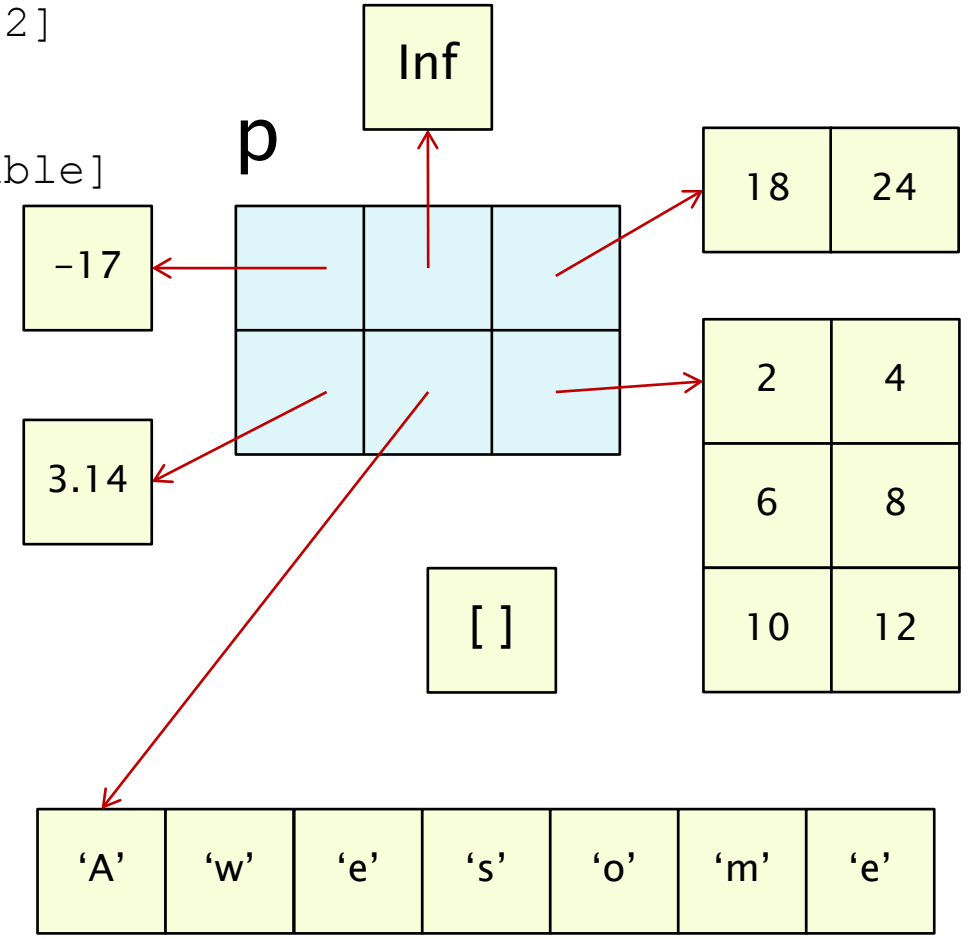
```
>> p{2,3} = [2 4; 6 8; 10 12]
P =
    [-17]   []       []
    [3.14] 'Awesome'[3x2 double]

>> p{1,3} = sum(p{2,3});
>> P{1,2} = 1/0;
>> class(p)
ans =
      cell
>>
```



Cell array example

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P =
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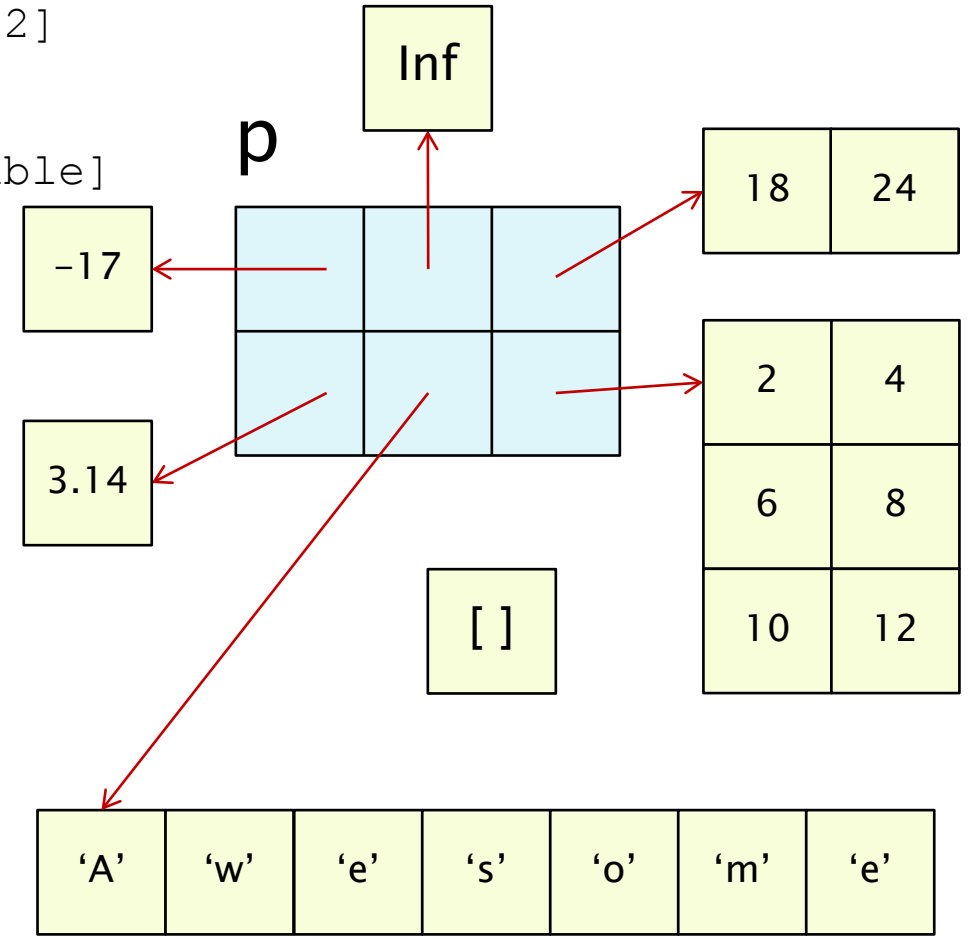
   [3.14] 'Awesome'[3x2 double]

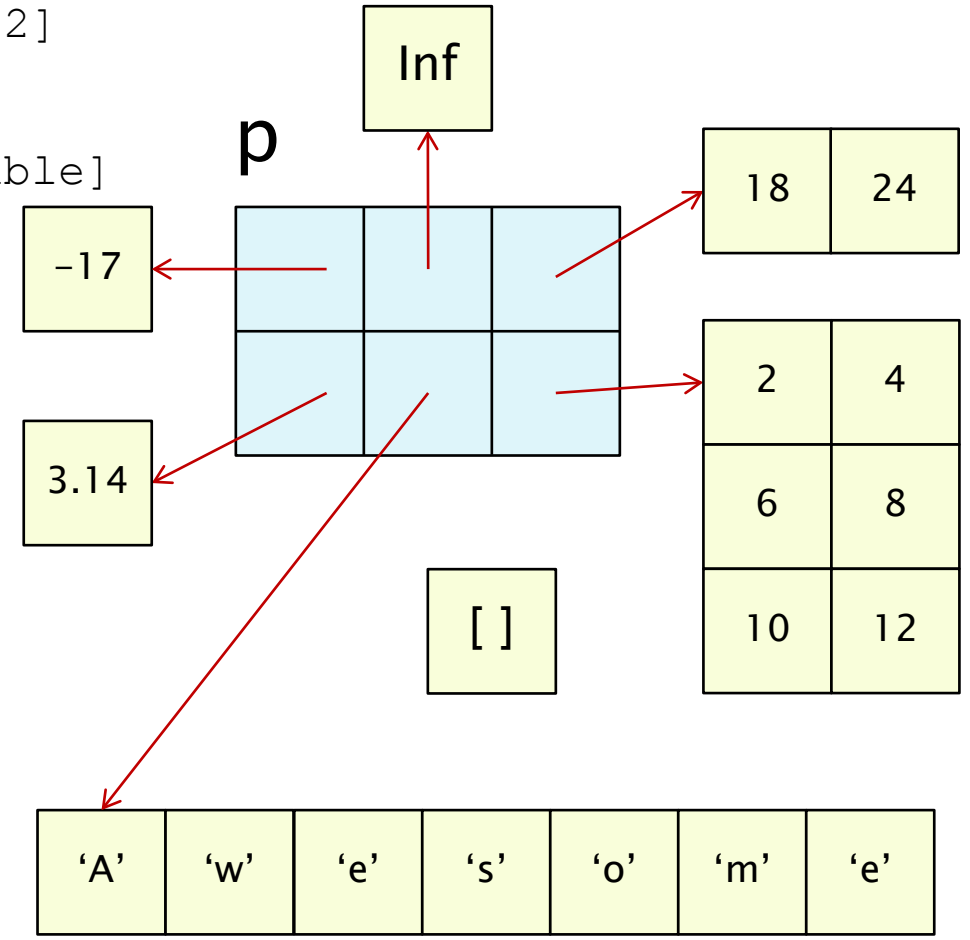
>> p{1,3} = sum(p{2,3});
>> P{1,2} = 1/0;
>> class(p)
ans =
      cell
>> class(p{1,2})
ans =
      double
>>
```



Cell array example

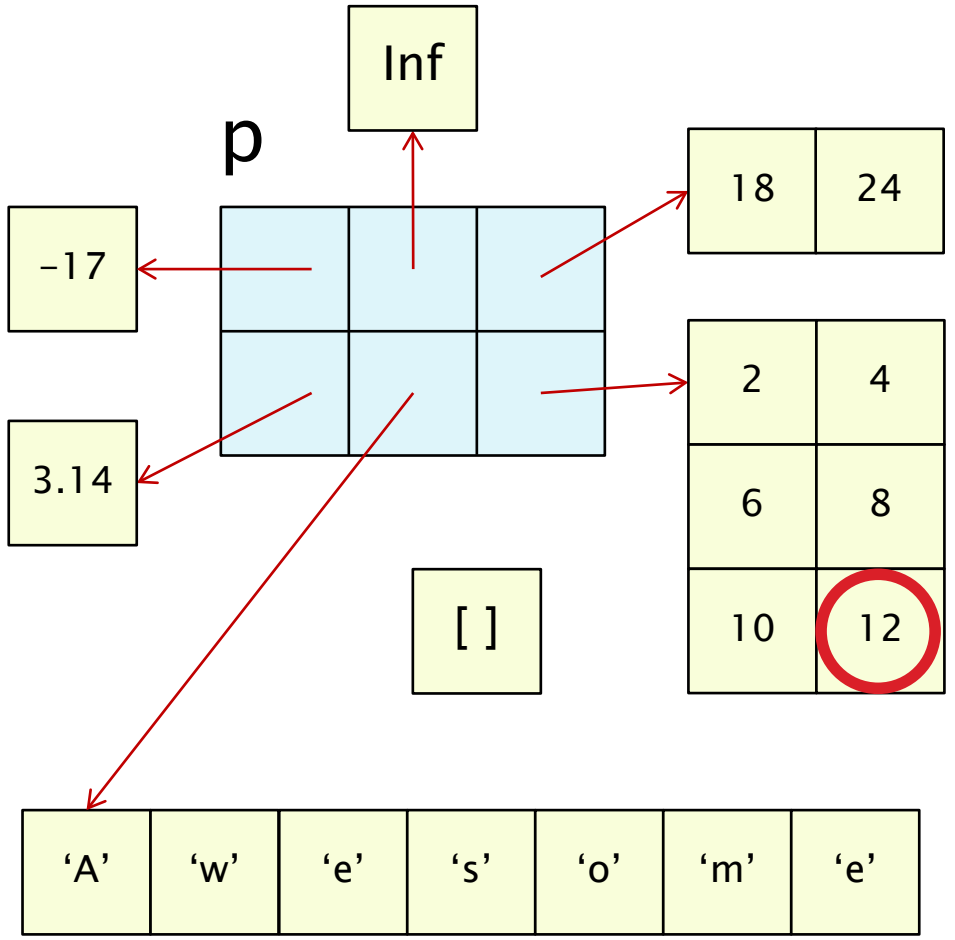
```
>> p{2,3} = [2 4; 6 8; 10 12]
P =
    [-17]   []       []
   [3.14] 'Awesome'[3x2 double]

>> p{1,3} = sum(p{2,3});
>> P{1,2} = 1/0;
>> class(p)
ans =
      cell
>> class(p{1,2})
ans =
      double
>> class(p(1,2))
ans =
      cell
>>
```



Cell array example

```
>> p{2,3}(3,2)
ans =
      12
>>
```



Cell functions

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FUNCTION	DESCRIPTION
`cell`	create an array of type cell
`celldisp`	show all the objects pointed at by a cell array
`cellfun`	apply a function to all the objects pointed at by a cell array
`cellplot`	show a graphical depiction of the contents of a cell array
`cell2struct`	convert a cell array into a struct array
`deal`	copy a value into output arguments
`iscell`	returns true if argument is of type cell
`num2cell`	convert a numeric array into a cell array