Rethinking Arrays in R

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Davis Vaughan
@dvaughan32
Software Engineer, RStudio

Array manipulation in R is **inconsistent** and doesn't follow natural **intuition**.

Arrays are:

1. *frustrating* to work with.

2. *difficult* to program around.

3. *underpowered*.

Subsetting

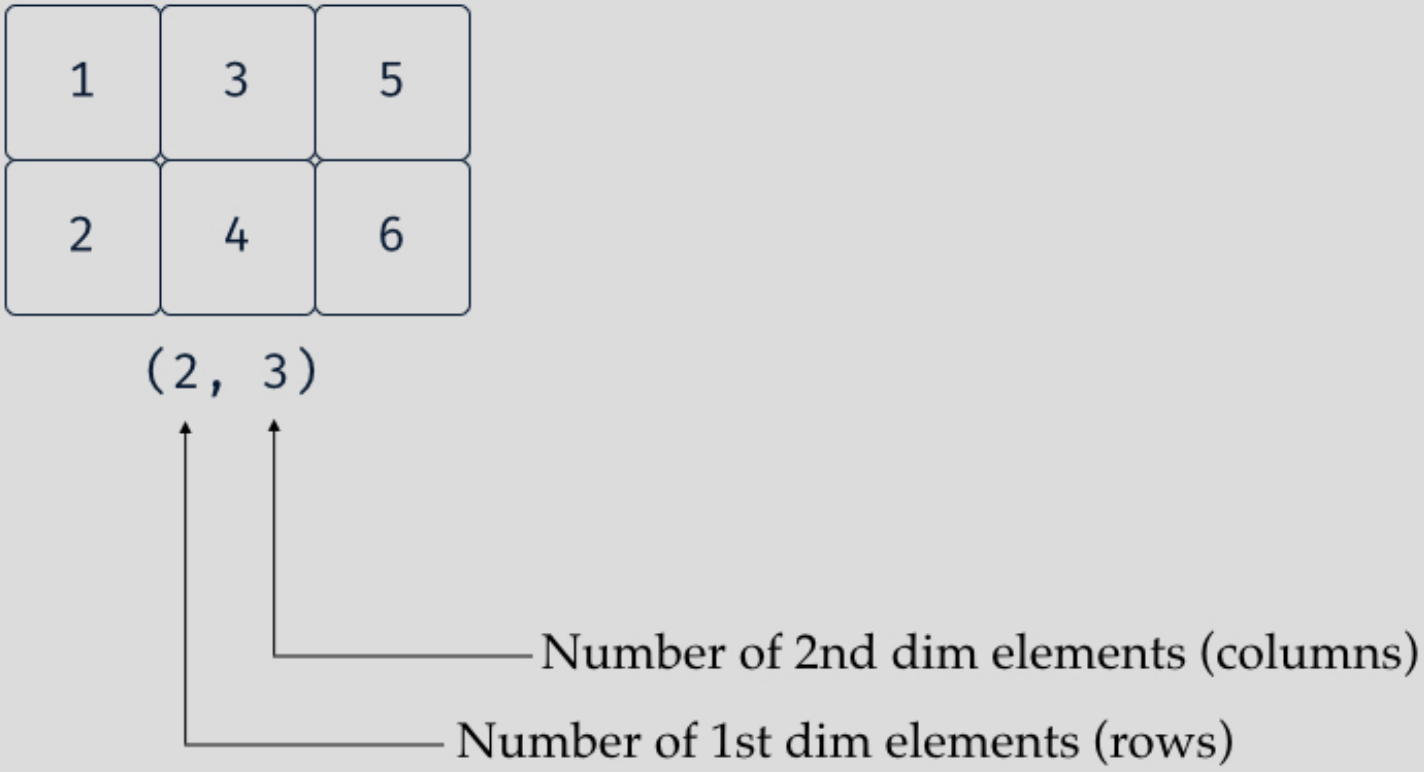
Broadcasting

Manipulation

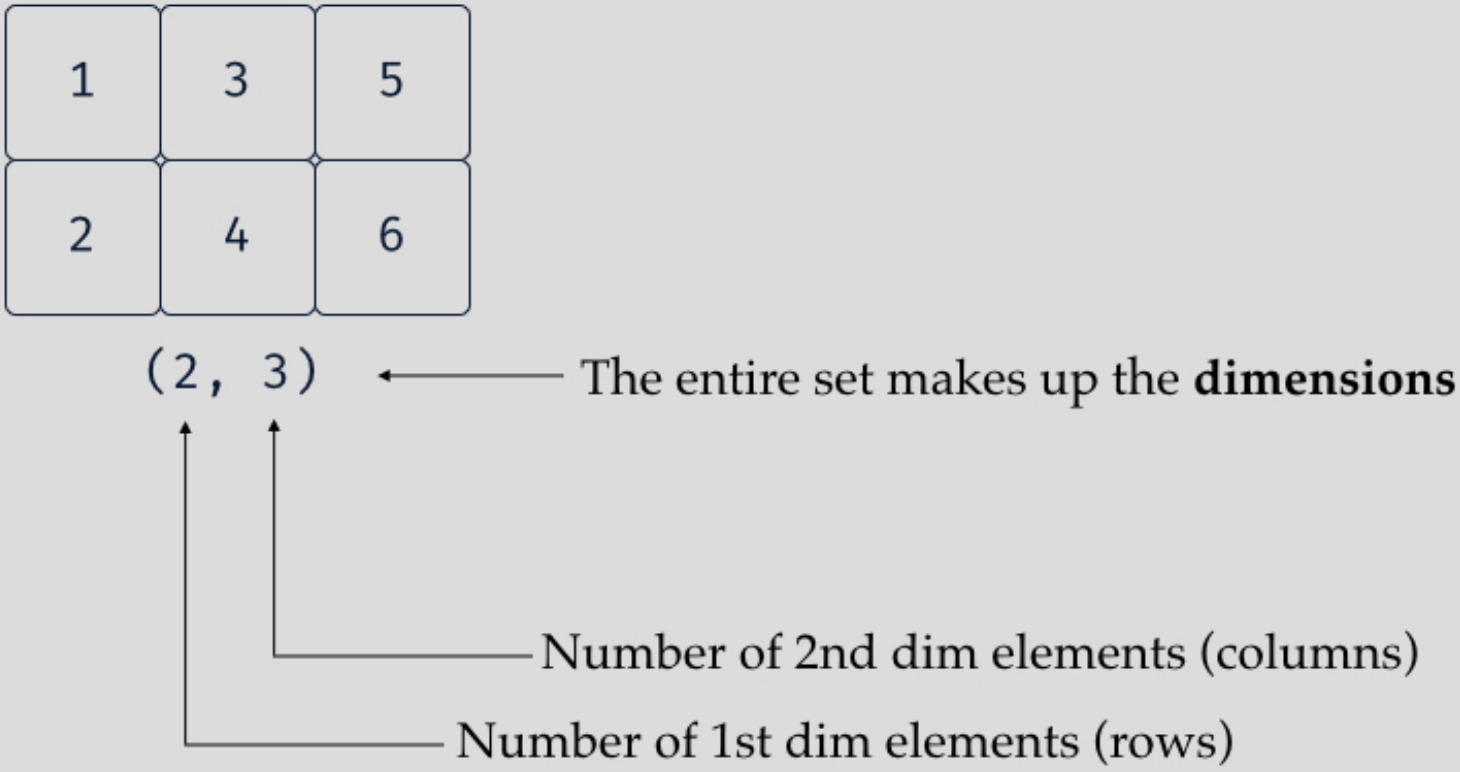
dimensionality:
The number of dimensions in an array.

dimensions:
The set of lengths describing the shape of the array.

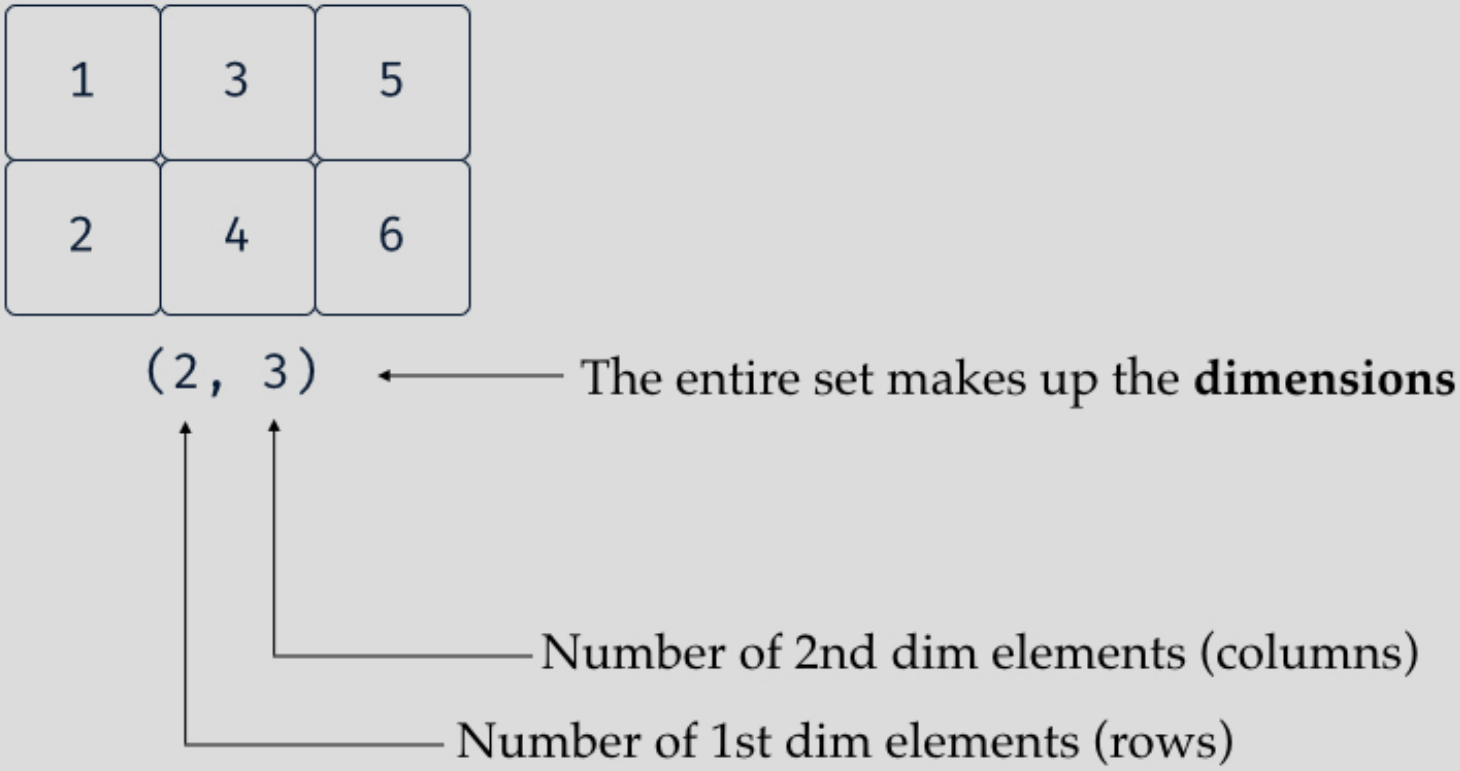
dimensionality VS dimensions



dimensionality VS dimensions



dimensionality VS dimensions



The **dimensionality** is 2
(2D object)

Subsetting

Enter the matrix.

x

Column selection

`x`

`x[, 1:2]`

One column?

1	3	5
2	4	6

x

?

```
x[, 1]
```

One column?

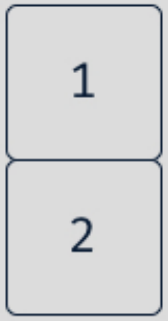
x

```
1     2
```

x[, 1]

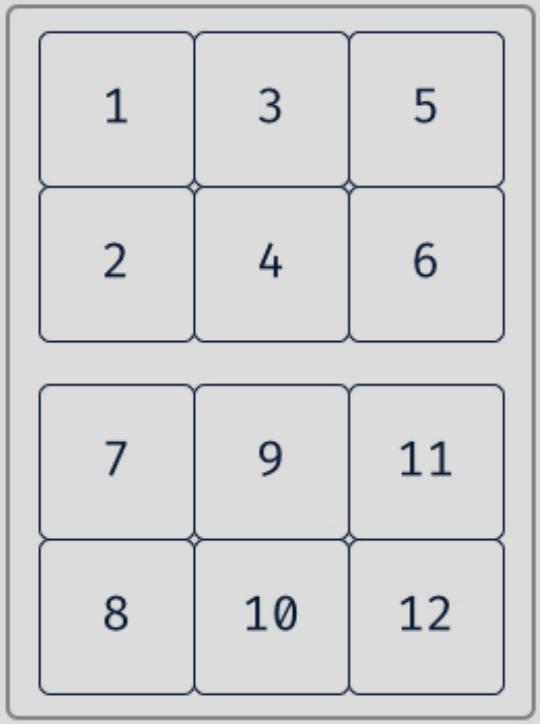
Oh! Let me fix that for you…

`x`




```
x[, 1, drop = FALSE]
```

Let's go 3D



y

?

y[, 1:2]

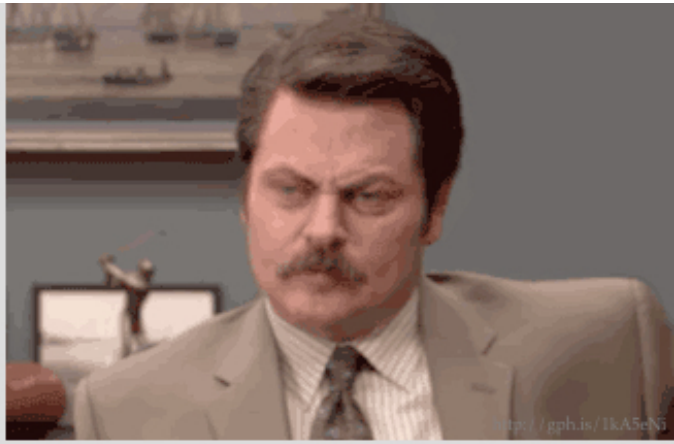
Let's go 3D

y

```
Error:
incorrect number
  of dimensions
```

```
y[, 1:2]
```

Let's go 3D



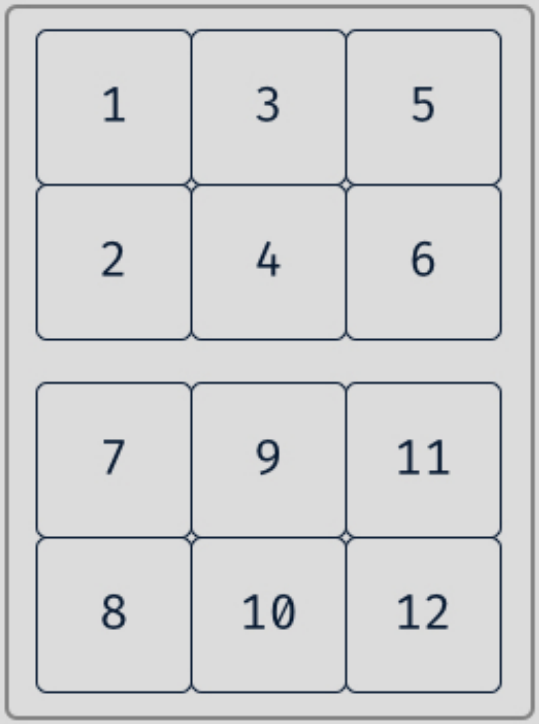
1	3	5
2	4	6
7	9	11
8	10	12

y

```
Error:
incorrect number
  of dimensions
```

```
y[, 1:2]
```

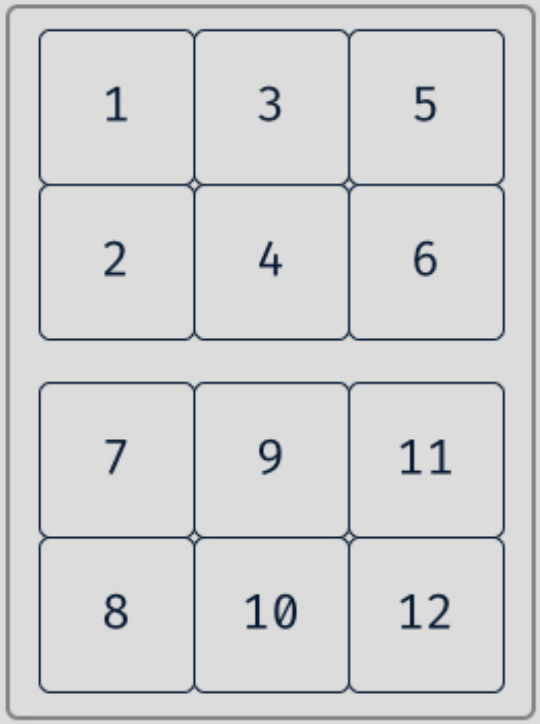
Let's go 3D



y

y[, 1:2,]

One column?

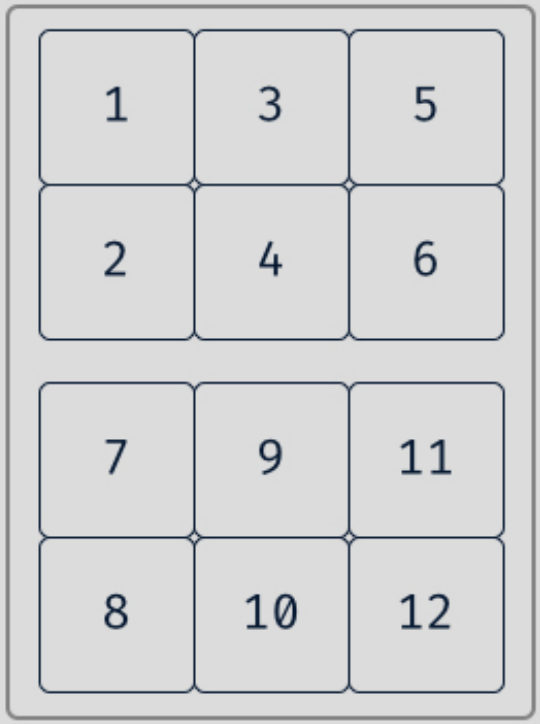


y

?

y[, 1,]

One column?



y

`y[, 1,]`

One column?

y

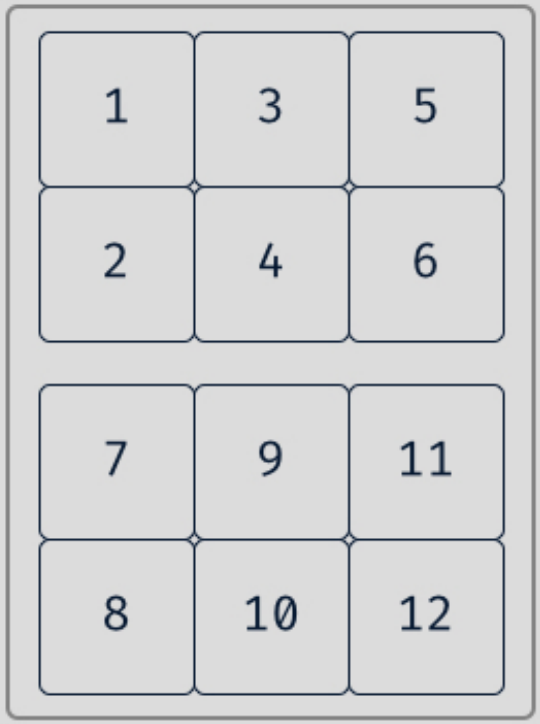
`y[, 1,]`

One column?

y

y[, 1,]

Oh! Let me fix that for you…



`y`

`y[, 1, , drop = FALSE]`

The confusion?

Subsetting is not **dimensionality-stable**.

Summary: column selection = 😈

How Many?	Drops?	2D	3D
1	No	`x[, 1, drop = F]`	`x[, 1, , drop = F]`
>1	No	`x[, 1:2]`	`x[, 1:2, ]`
1	Yes	`x[, 1]`	`x[, 1, ]`*
>1	Yes	`x[, 1:2, drop = T]`	`x[, 1:2, , drop = T]`

* Drops to 2D

Summary: column selection = 😈

How Many?	Drops?	2D	3D
1	No	`x[, 1, drop = F]`	`x[, 1, , drop = F]`
>1	No	`x[, 1:2]`	`x[, 1:2, ]`
1	Yes	`x[, 1]`	`x[, 1, ]`*
>1	Yes	`x[, 1:2, drop = T]`	`x[, 1:2, , drop = T]`

* Drops to 2D

Summary: column selection = 🎉

How Many?	Drops?	2D	3D	Proposed
1	No	`x[, 1, drop = F]`	`x[, 1, , drop = F]`	`x[, 1]`
>1	No	`x[, 1:2]`	`x[, 1:2, ]`	`x[, 1:2]`
1	Yes	`x[, 1]`	`x[, 1, ]`*	`x[[, 1]]`
>1	Yes	`x[, 1:2, drop = T]`	`x[, 1:2, , drop = T]`	`x[[, 1:2]]`

* Drops to 2D

Summary: column selection = 🎉

How Many?	Drops?	2D	3D	Proposed
1	No	`x[, 1, drop = F]`	`x[, 1, , drop = F]`	`x[, 1]`
>1	No	`x[, 1:2]`	`x[, 1:2, ]`	`x[, 1:2]`
1	Yes	`x[, 1]`	`x[, 1, ]`*	`x[[, 1]]`
>1	Yes	`x[, 1:2, drop = T]`	`x[, 1:2, , drop = T]`	`x[[, 1:2]]`

* Drops to 2D

Summary: column selection = 🎉

How Many?	Drops?	2D	3D	Proposed
1	No	`x[, 1, drop = F]`	`x[, 1, , drop = F]`	`x[, 1]`
>1	No	`x[, 1:2]`	`x[, 1:2, ]`	`x[, 1:2]`
1	Yes	`x[, 1]`	`x[, 1, ]`*	`x[[, 1]]`
>1	Yes	`x[, 1:2, drop = T]`	`x[, 1:2, , drop = T]`	`x[[, 1:2]]`

* Drops to 2D

rray

`rray` is designed to provide a **stricter** array class.

Create an rray

```
library(rray)

x ← matrix(1:6, nrow = 2)
x
#>      [,1] [,2] [,3]
#> [1,]    1    3    5
#> [2,]    2    4    6

x_rray ← as_rray(x)
x_rray
#> <vctrs_rray<integer>[,3][6]>
#>      [,1] [,2] [,3]
#> [1,]    1    3    5
#> [2,]    2    4    6
```

Column subsetting…round two

`x_rray`

`x_rray[, 1]`

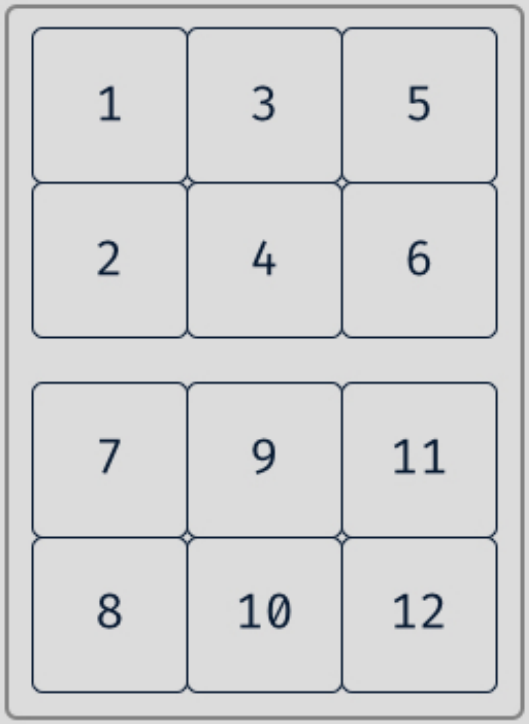
`x_rray[, 1:2]`

`y_rray`

`y_rray[, 1]`

`y_rray[, 1:2]`

[[always drops to 1D



y_rray

```
1     2     7     8
```

y_rray[[, 1]]

Broadcasting

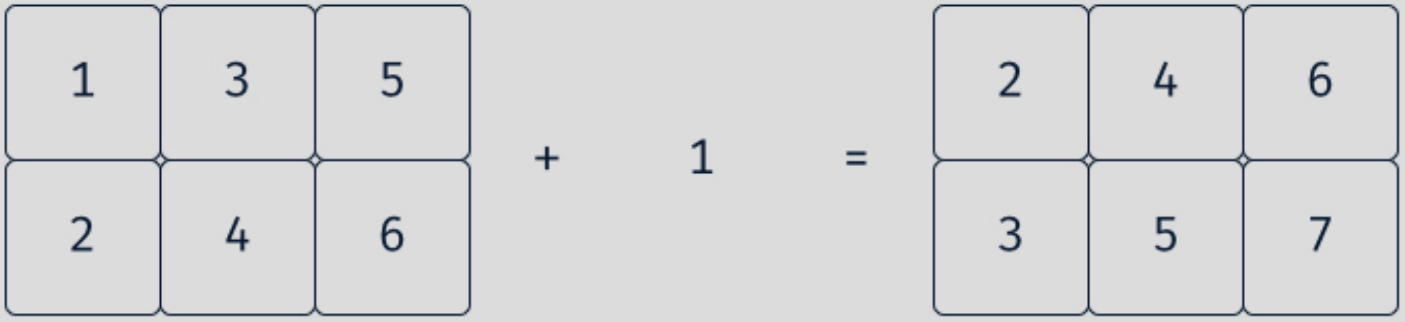
Broadcasting has to do with **increasing dimensionality** and **recycling dimensions.**

Let's do some math

+ 1 =

x: (2, 3) y: (1)

Let's do some math



`x: (2, 3)` `y: (1)` `(2, 3)`

How is y reshaped
so that this works?

Step 1 - increase dimensionality

```
x: (2, 3)
y: (1)
-----------
   (?, ?)
```

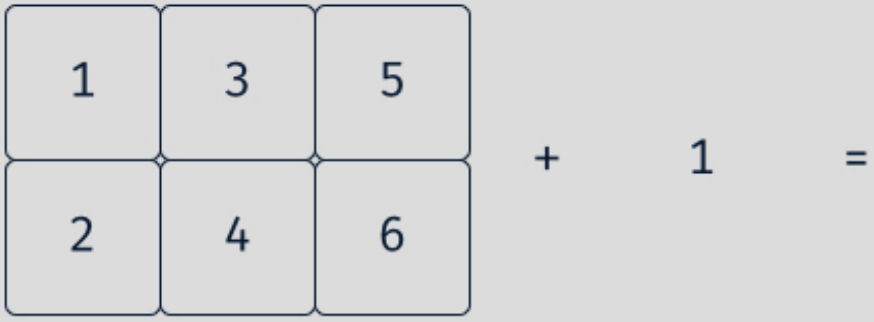
Dimensionality of **2**

Dimensionality of **1**

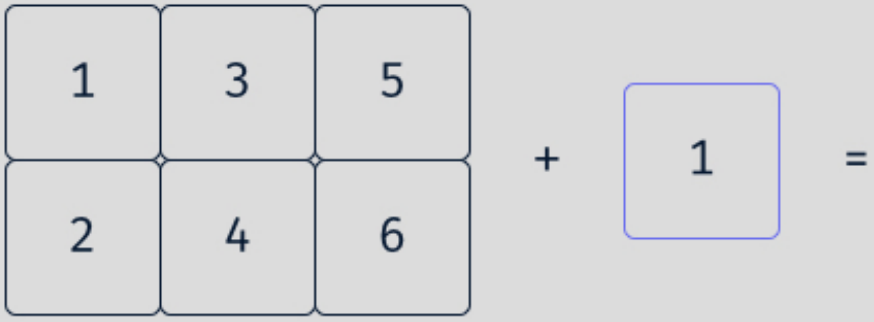
Append 1's **to the dimensionality of y until it matches the dimensionality of x**

```
x: (2, 3)
y: (1, 1)
-----------
   (?, ?)
```

Step 1 - increase dimensionality



x: (2, 3) y: (1)



x: (2, 3) y: (1, 1)

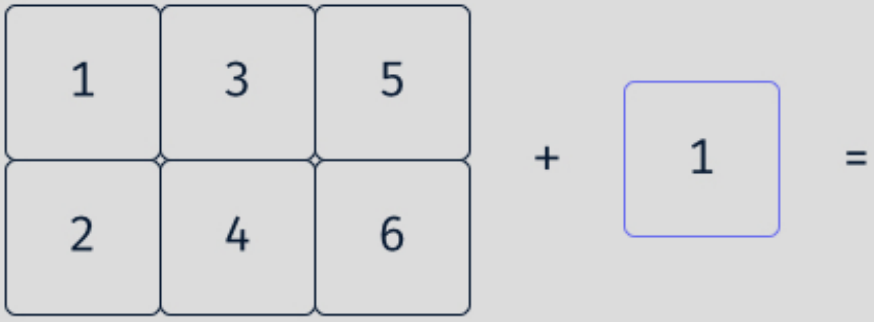
Step 2 - recycle dimensions

```
x: (2, 3)
y: (1, 1)
-----------
   (?, ?)
```

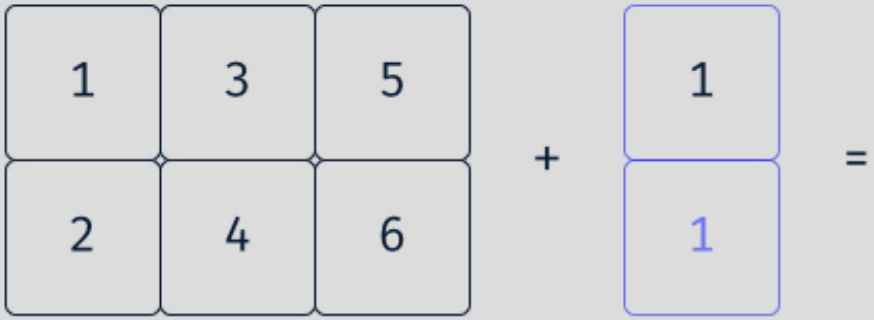
If the rows of `y` were *recycled* to length 2, it would match the length of the rows of `x`

```
x: (2, 3)
y: (2, 1)
-----------
   (2, ?)
```

Step 2 - recycle dimensions



x: (2, 3) y: (1, 1)



x: (2, 3) y: (2, 1)

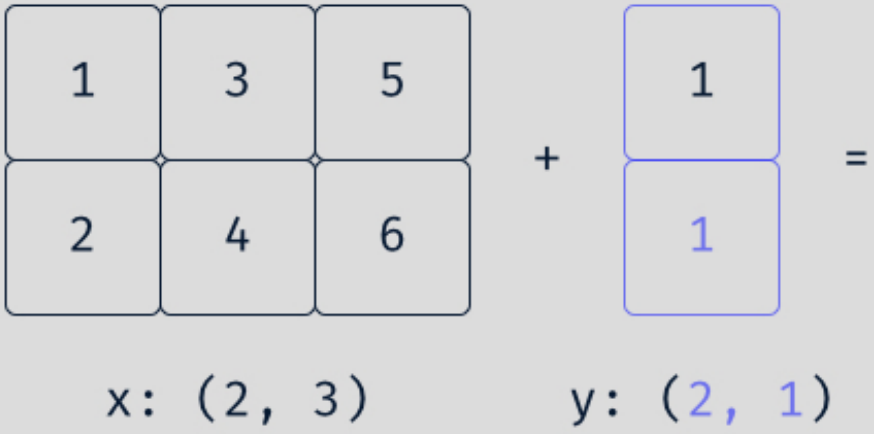
Step 2 - recycle dimensions

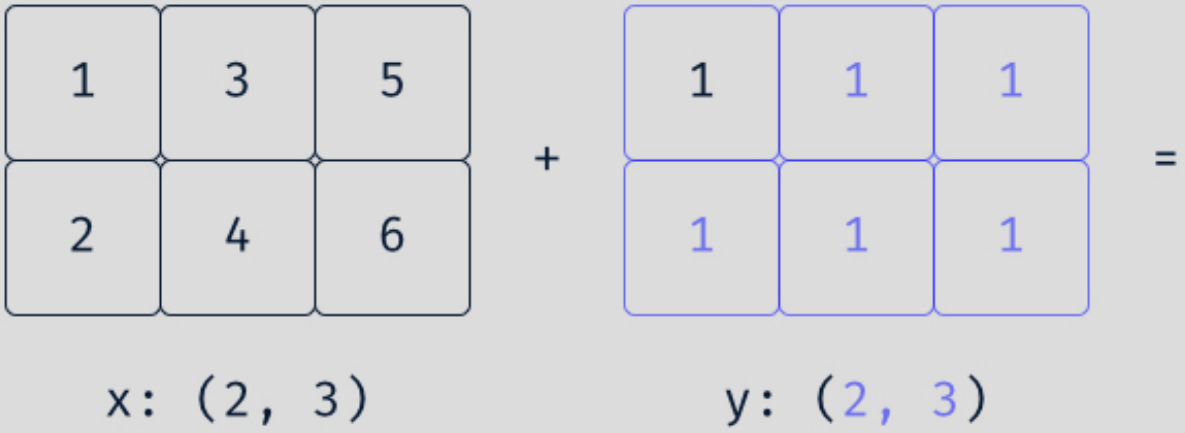
```
x: (2, 3)
y: (2, 1)
──────────
   (2, ?)
```

If the columns of `y` were *recycled* to length 3, it would match the length of the columns of `x`

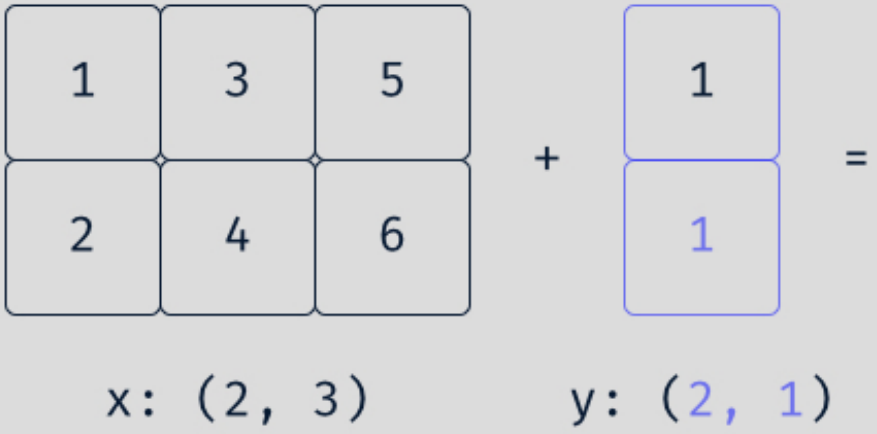
```
x: (2, 3)
y: (2, 3)
──────────
   (2, 3)
```

Step 2 - recycle dimensions

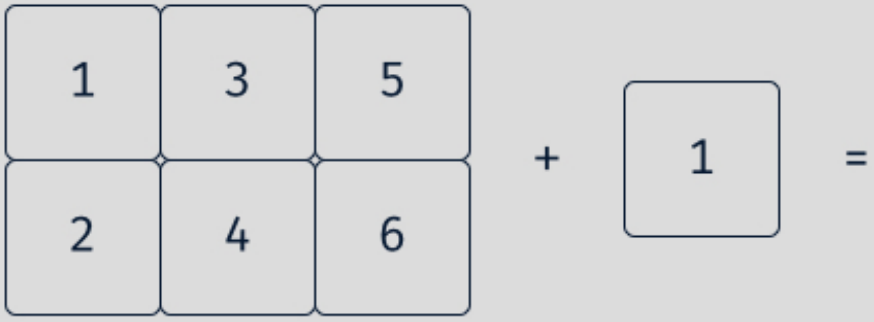




Step 2 - recycle dimensions

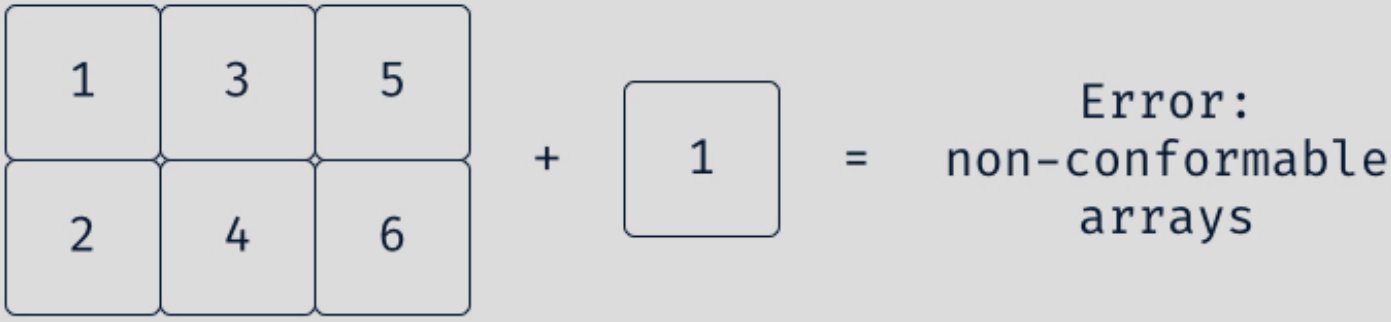


What if we started here?



`x: (2, 3)` `y: (1, 1)`

What if we started here?



What if we started here?

1	3	5
2	4	6

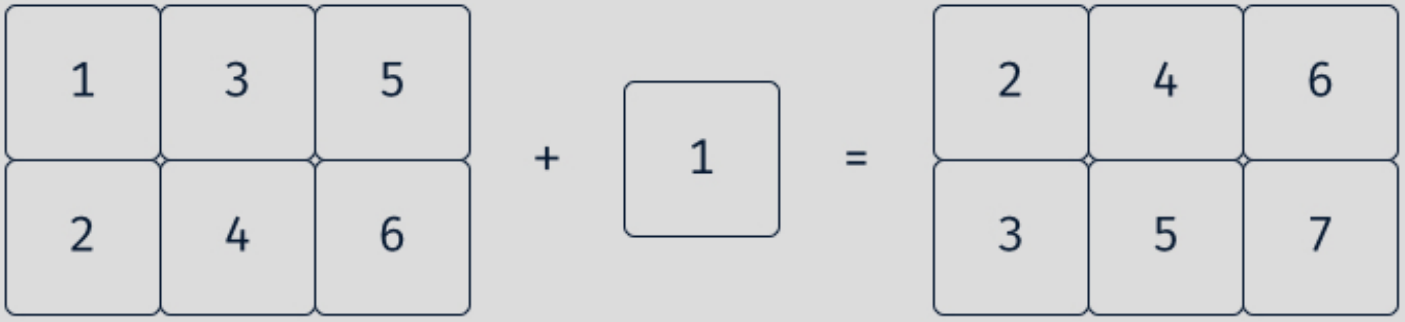
+ | 1 | = Error: non-conformable arrays

x: (2, 3) y: (1, 1)

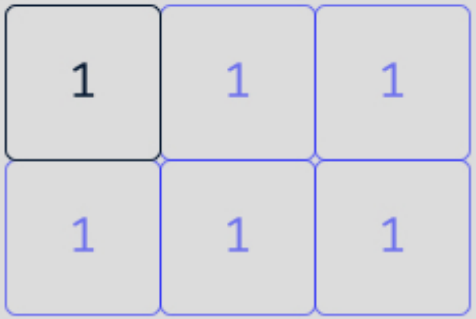
R doesn't broadcast.

We just got lucky that it worked with scalars.

We know the result



`x: (2, 3)` `y: (1, 1)` `(2, 3)`



`y: (2, 3)`

Broadcasting rules:

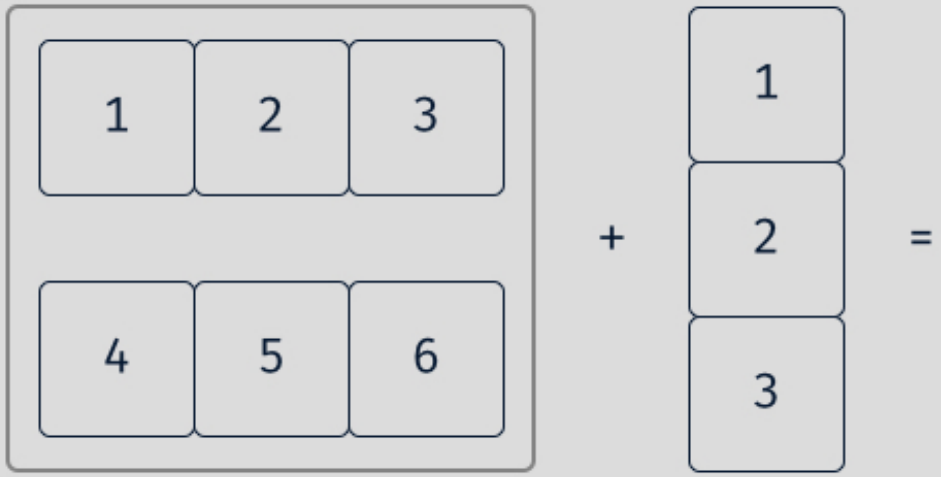
Match **dimensionality** by *appending 1's*

Match **dimensions** by *recycling* dimensions of length 1

rray broadcasts

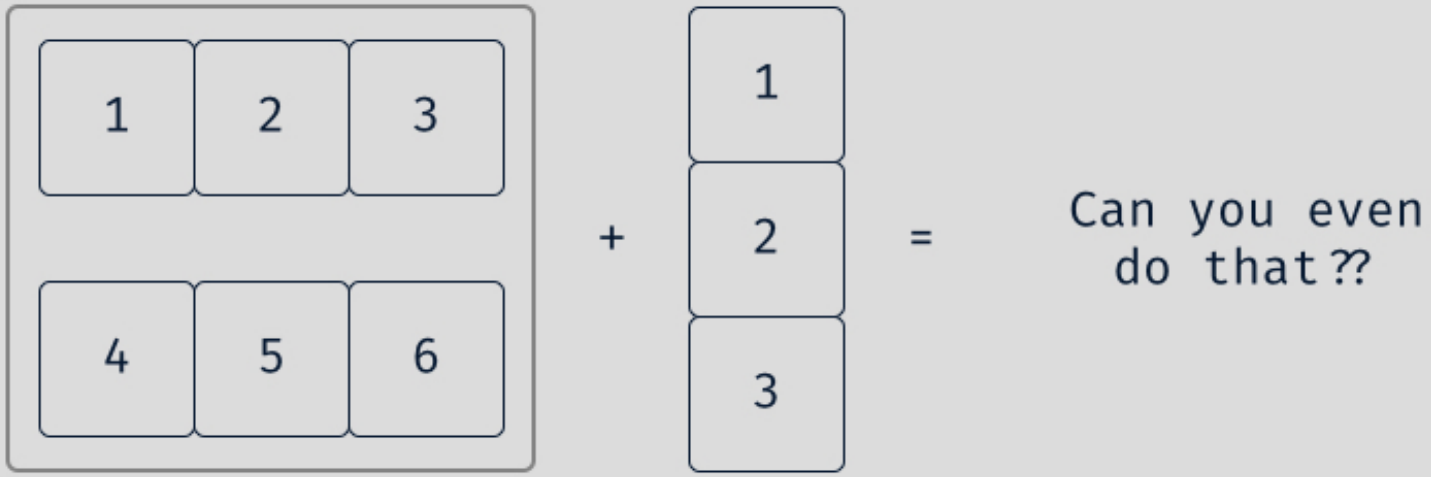
```
library(rray)

x ← matrix(1:6, nrow = 2)
x
#>      [,1] [,2] [,3]
#> [1,]    1    3    5
#> [2,]    2    4    6

z ← matrix(1)
z
#>      [,1]
#> [1,]    1

x + z
#> Error in x + z : non-conformable arrays

as_rray(x) + z
#> <vctrs_rray<double>[,3][6]>
#>      [,1] [,2] [,3]
#> [1,]    2    4    6
#> [2,]    3    5    7
```

Let's go 3D



`x: (1, 3, 2)` `y: (3, 1)`

Let's go 3D

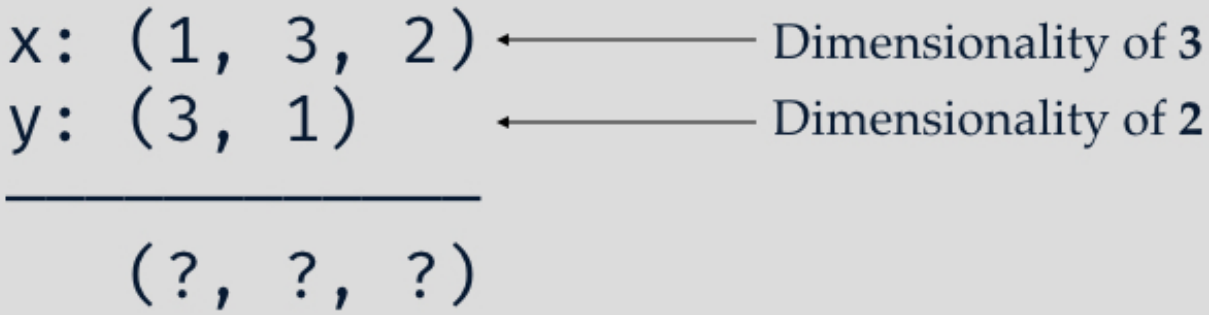


Can you even do that??

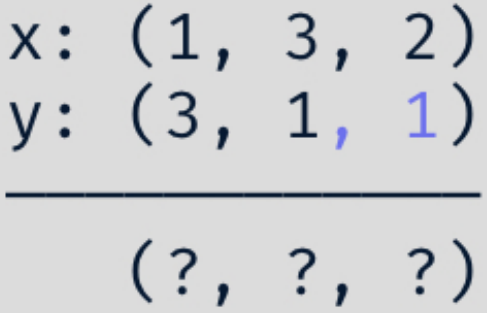
x: (1, 3, 2)

y: (3, 1)

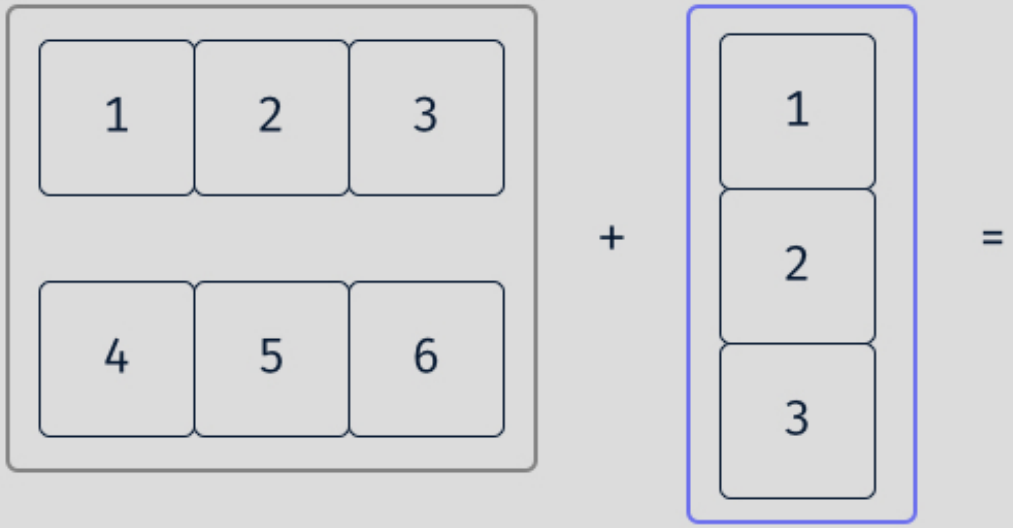
Step 1 - increase dimensionality



Append 1's **to the dimensionality of y until it matches the dimensionality of x**

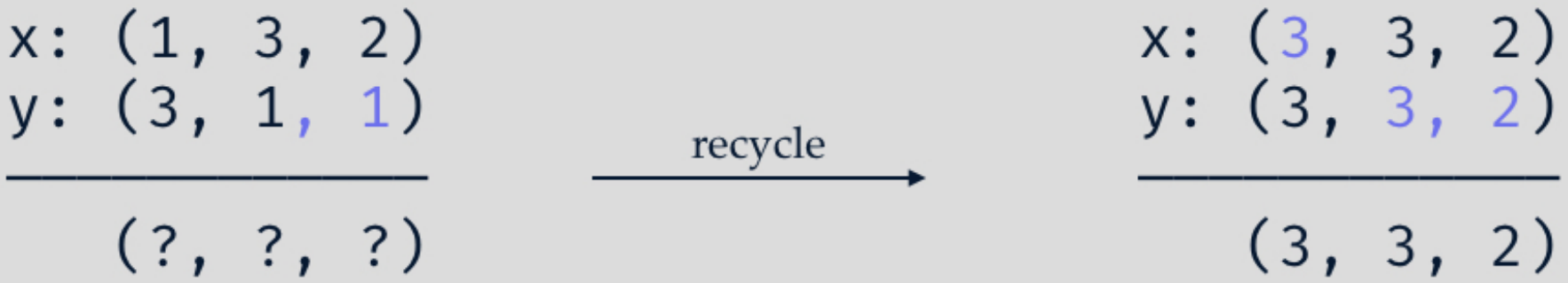


Step 1 - increase dimensionality

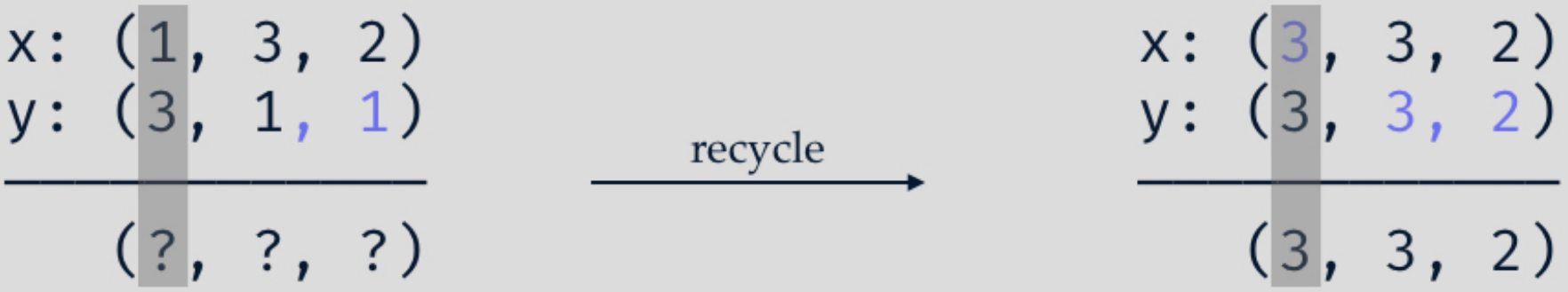


`x: (1, 3, 2)` `y: (3, 1, 1)`

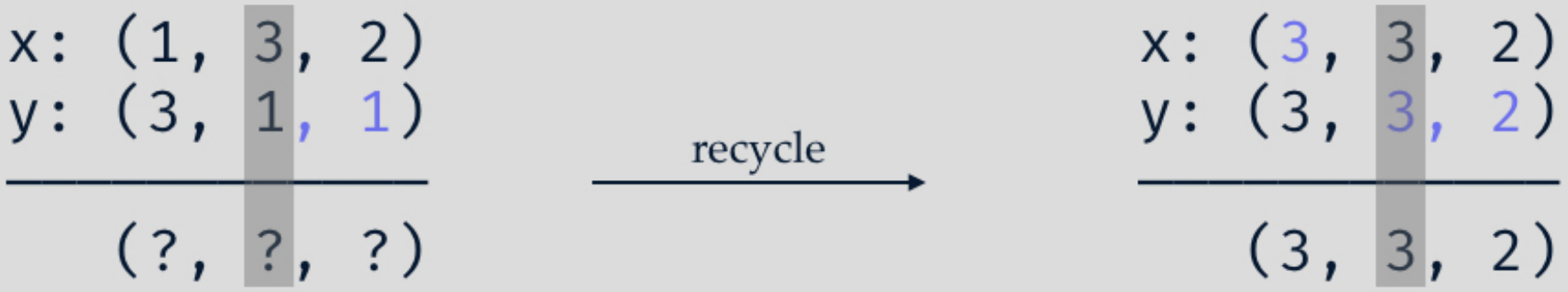
Step 2 - recycle dimensions



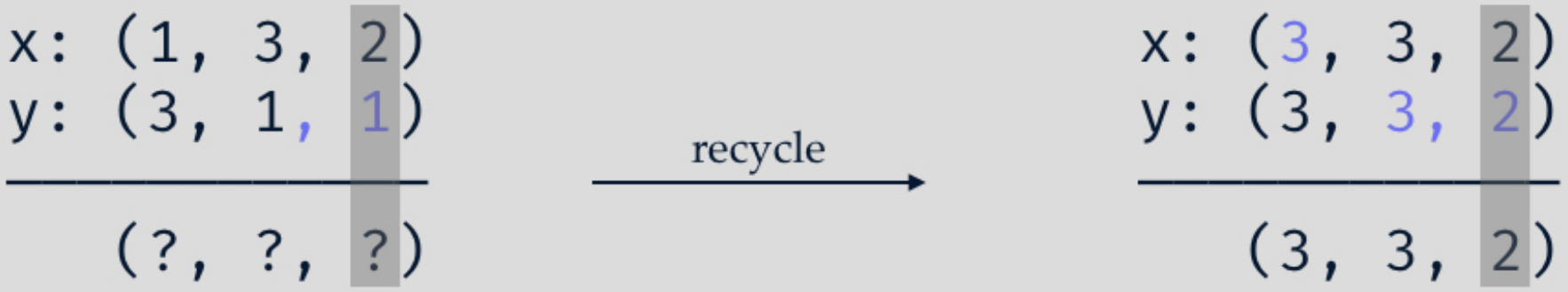
Step 2 - recycle dimensions



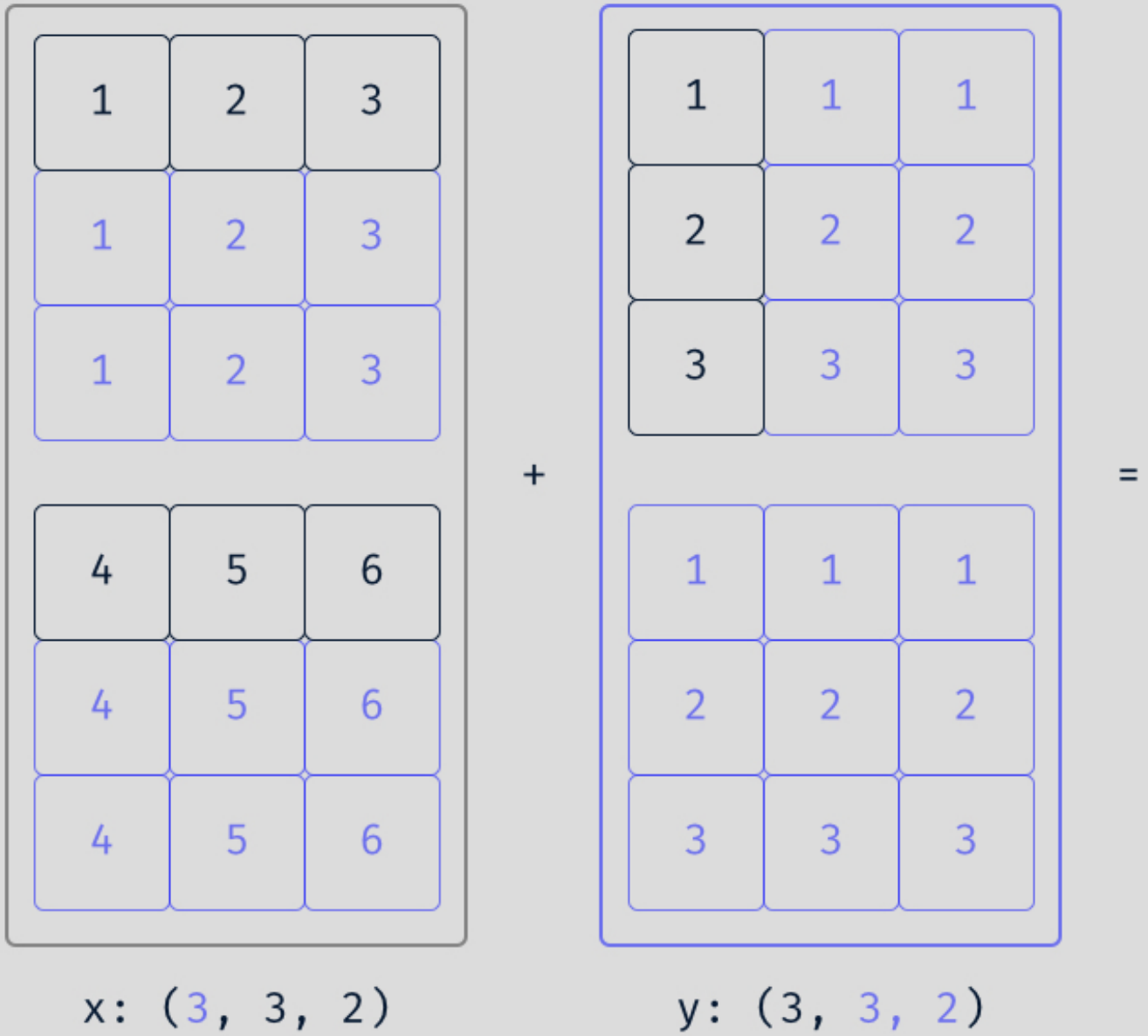
Step 2 - recycle dimensions



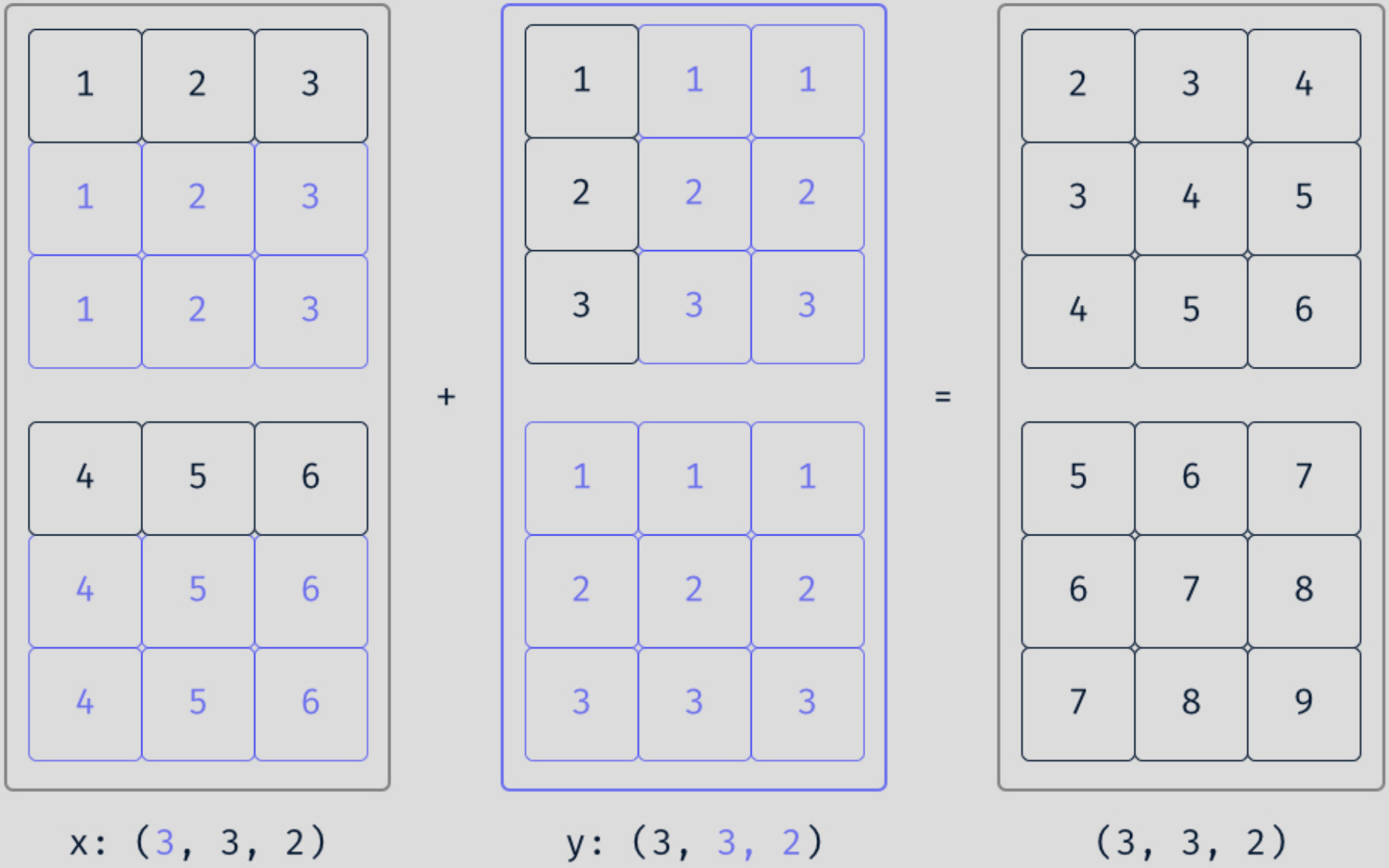
Step 2 - recycle dimensions



Step 2 - recycle dimensions



Step 2 - recycle dimensions



Manipulation

rray as a toolkit

```
rray_bind()
rray_duplicate_any()
rray_expand_dims()
rray_broadcast()
rray_flip()
rray_max()
rray_sum()
```

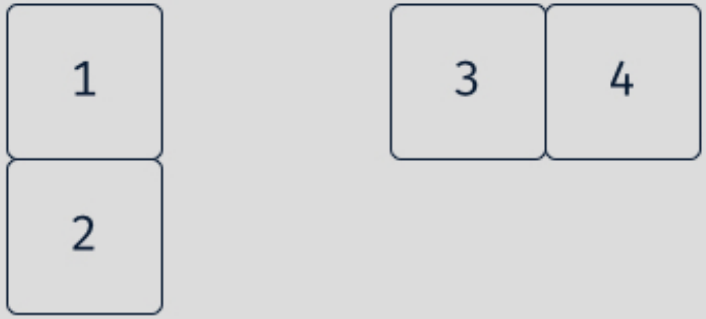
```
rray_mean()
rray_reshape()
rray_rotate()
rray_split()
rray_tile()
rray_unique()
…
```

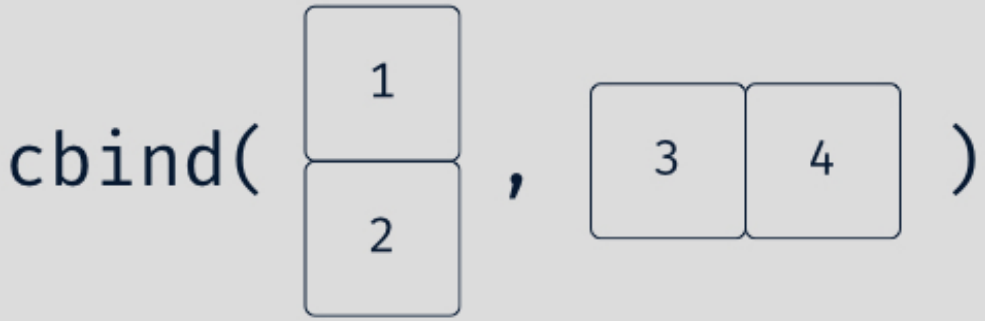
rray as a toolkit

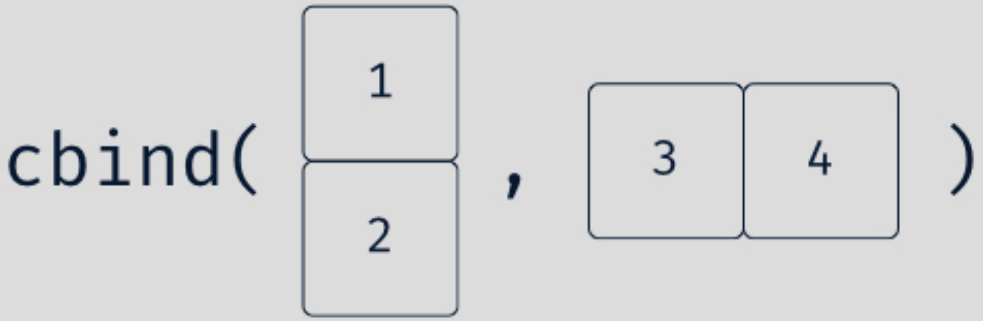
```
rray_bind()
rray_duplicate_any()
rray_expand_dims()
rray_broadcast()
rray_flip()
rray_max()
rray_sum()
```

```
rray_mean()
rray_reshape()
rray_rotate()
rray_split()
rray_tile()
rray_unique()
…
```

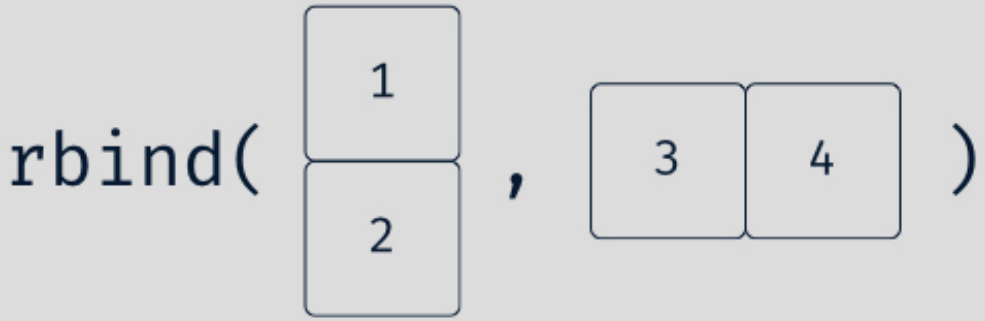
How can we bind these together?

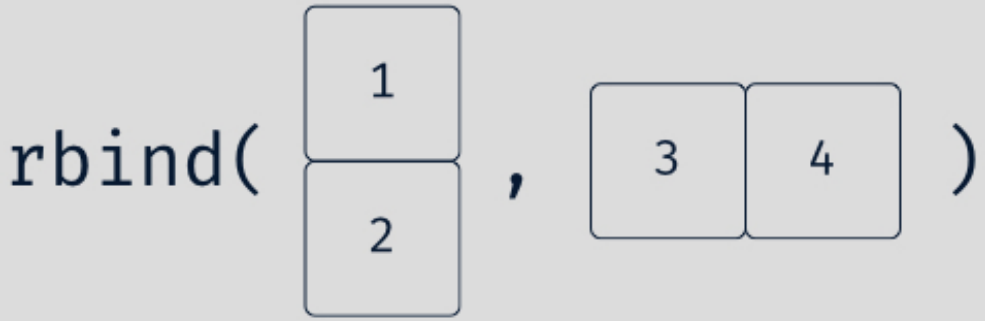



cbind(
1
2
,
3
4
)

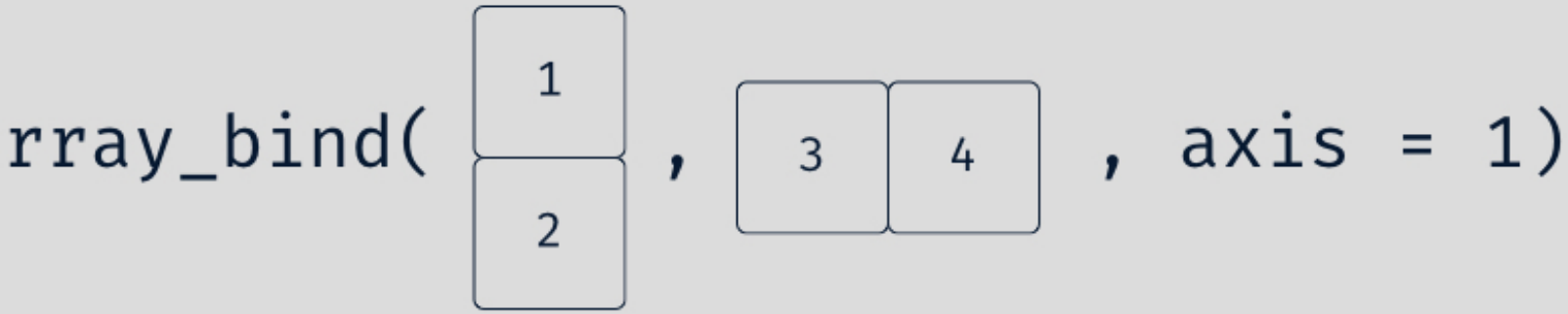


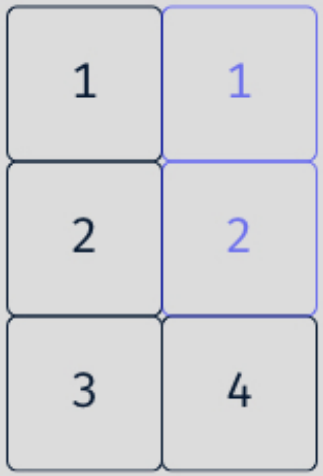
Error:
number of rows
of matrices must match


rbind(
1
2
,
3
4
)

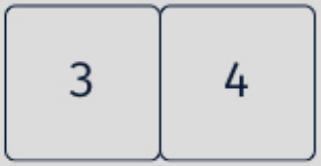


Error:
number of columns
of matrices must match

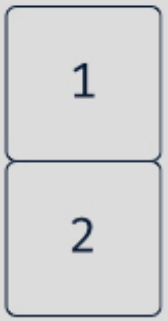

rray_bind(
1
2
,
3
4
, axis = 1)

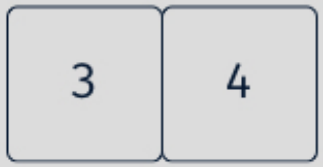

1
1
2
2
3
4

rray_bind(

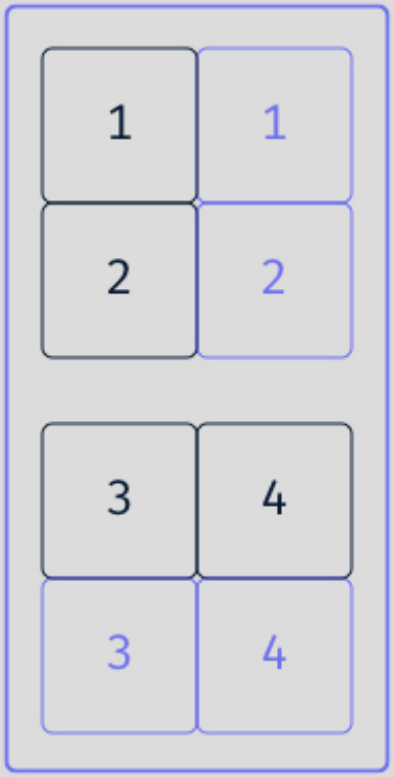
, 

, axis = 2)

rray_bind(

, 

, axis = 3)



rray as a toolkit

```
rray_bind()
rray_duplicate_any()
rray_expand_dims()
rray_broadcast()
rray_flip()
rray_max()
rray_sum()
rray_mean()
rray_reshape()
rray_rotate()
rray_split()
rray_tile()
rray_unique()
…
```

What if we want to “normalize” by dividing by the max value? Along columns? Along rows?

x / max(x)

1	3	5
2	4	6

.167	.500	.833
.333	.667	1

sweep(x, 1, apply(x, 1, max), “/")

1	3	5
2	4	6

.200	.600	1
.333	.667	1

sweep(x, 2, apply(x, 2, max), “/")

1	3	5
2	4	6

.500	.750	.833
1	1	1

```
x / rray_max(x)
```

1	3	5
2	4	6

.167	.500	.833
.333	.667	1

```
x / rray_max(x, axes = 2)
```

1	3	5
2	4	6

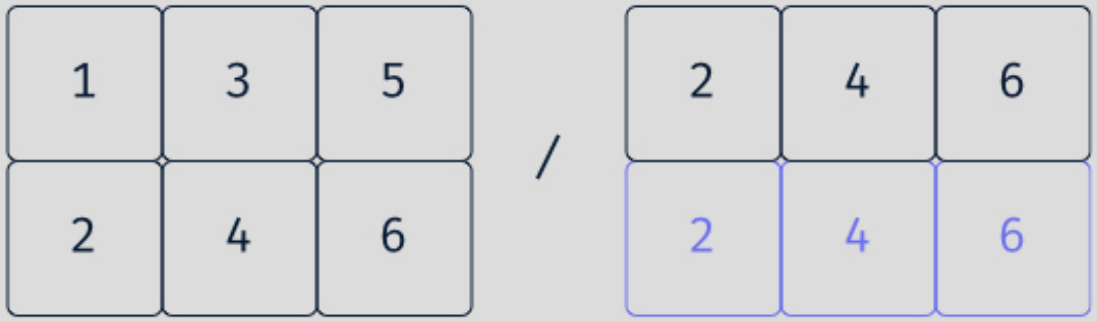
.200	.600	1
.333	.667	1

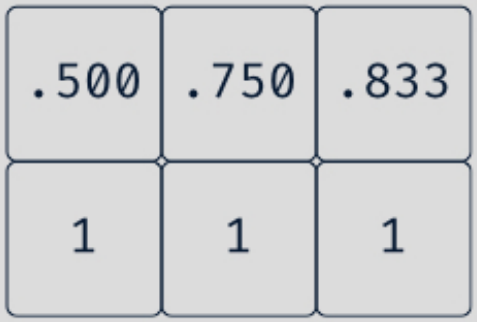
```
x / rray_max(x, axes = 1)
```

1	3	5
2	4	6

.500	.750	.833
1	1	1

```
x / rray_max(x, axes = 1)
```





Arrays are:

1. *frustrating* to work with.

2. *difficult* to program around.

3. *underpowered*.

Arrays are:

1. *intuitive* to work with.

2. *predictable* to program around.

3. *powerful*.