

# Mimicking memristors and other exotic circuit elements

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Workshop on Memristor Technology, Design, Automation and Computing

# Outline

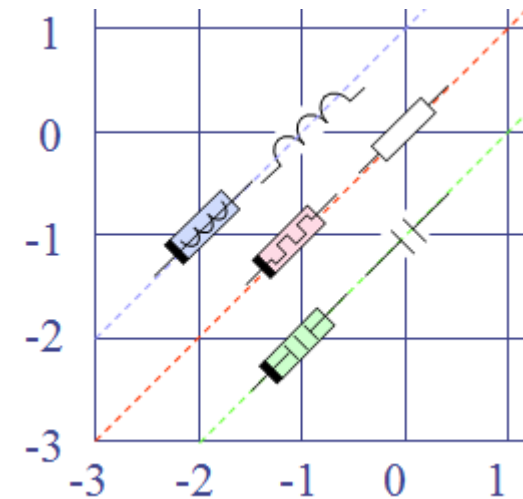
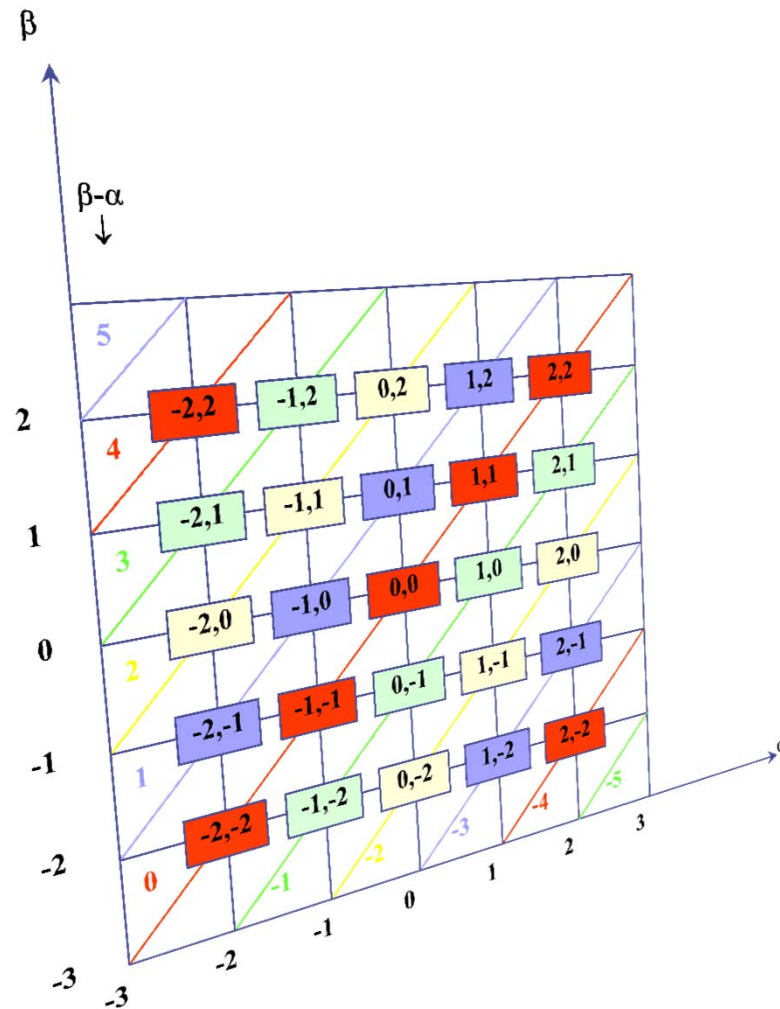


**\* Higher-order elements (HOEs) \* Emulating HOEs \* Mutator approach \*  
\* Hardware implementation \* Instead of Conclusions \***

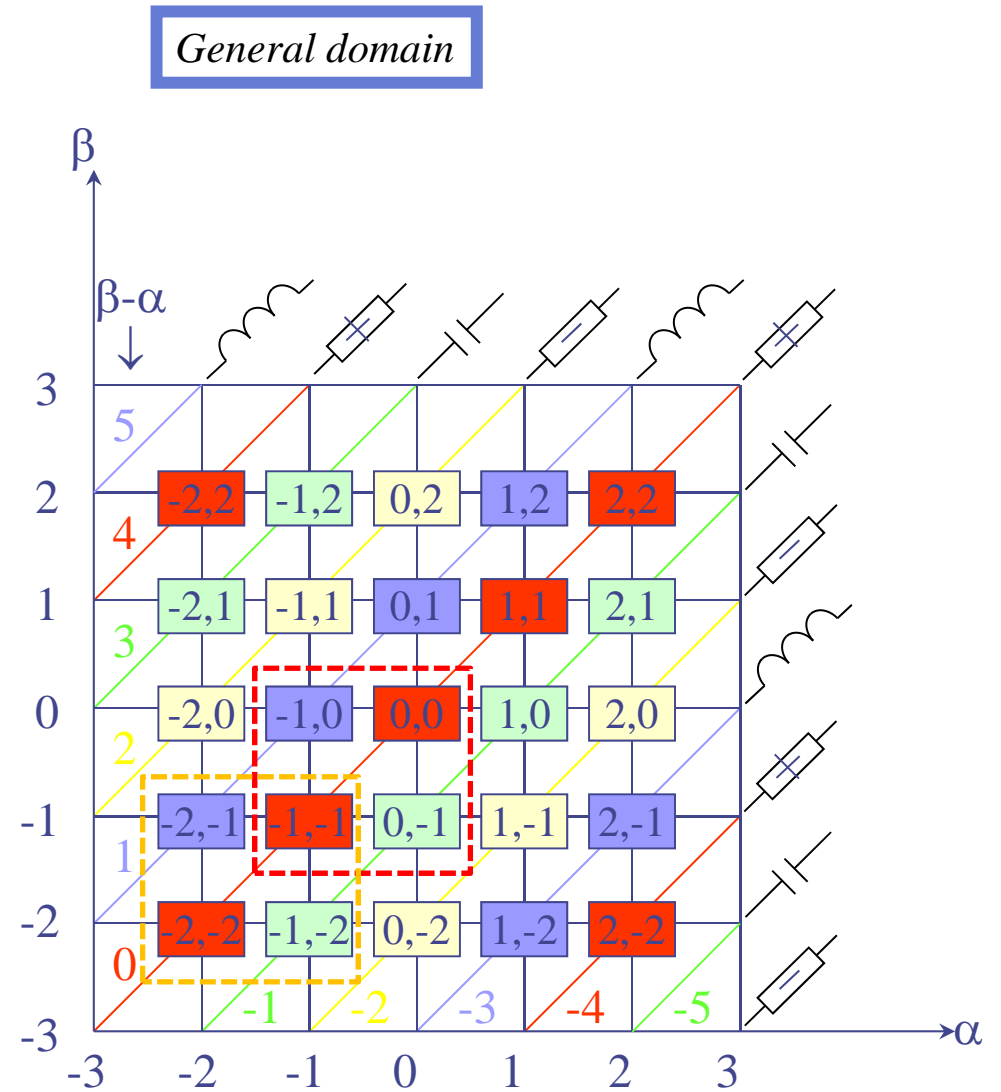
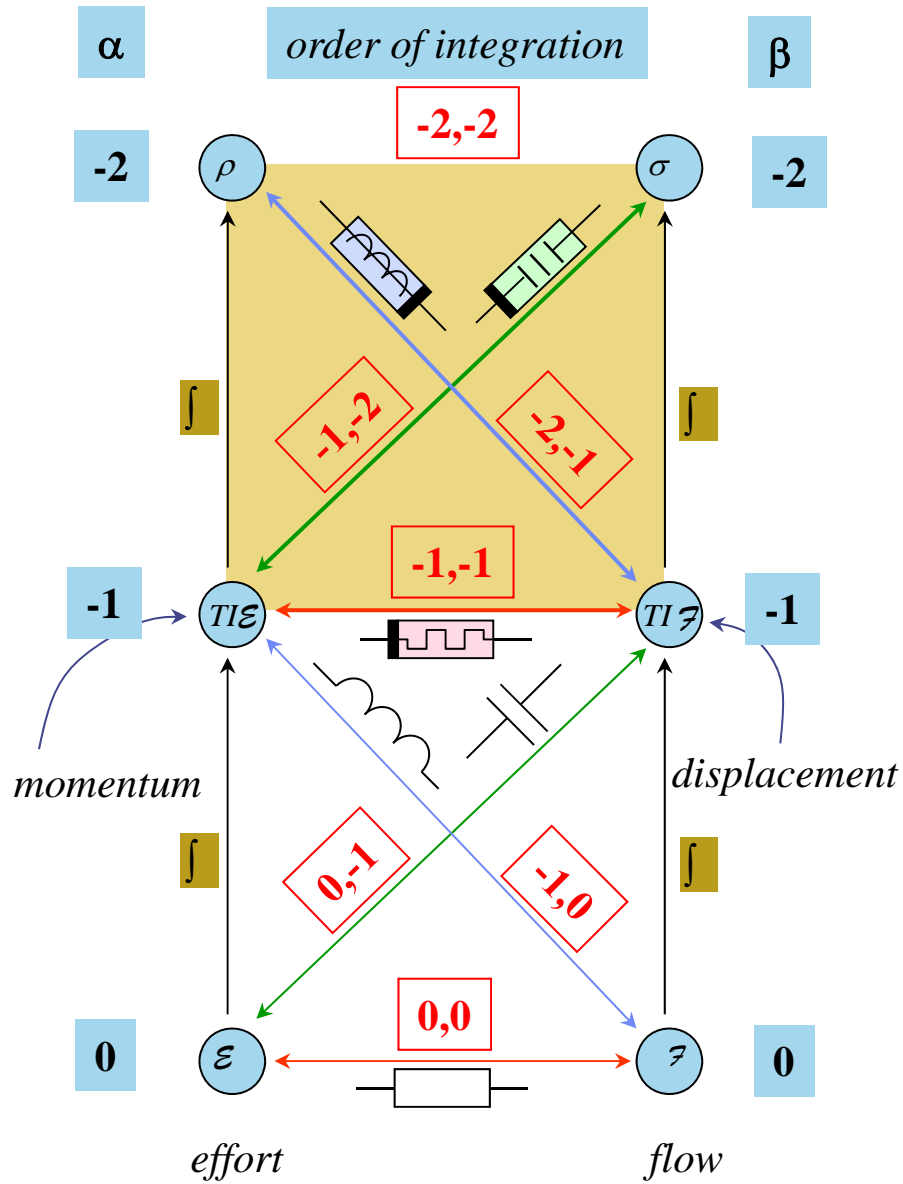
# Higher-Order $(\alpha, \beta)$ elements

*My situation was similar to that of the Russian chemist Dmitri Mendeleev who invented the periodic table in 1869. Mendeleev postulated that there were elements missing from the table, and now all those elements have been found. Likewise, Stanley Williams at HP Labs has now found the first example of the missing memristor circuit element."*

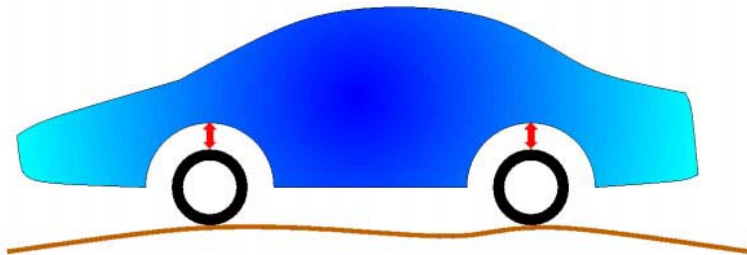
**Leon O. Chua**



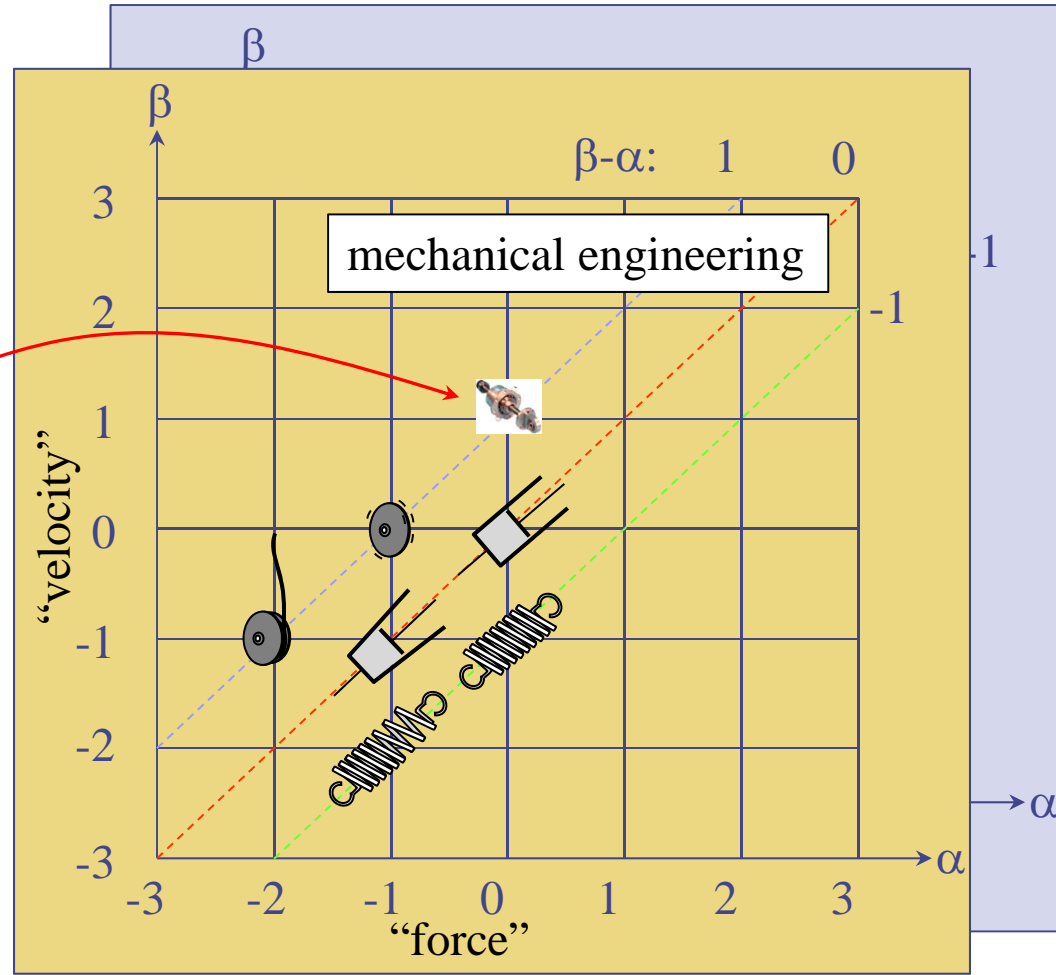
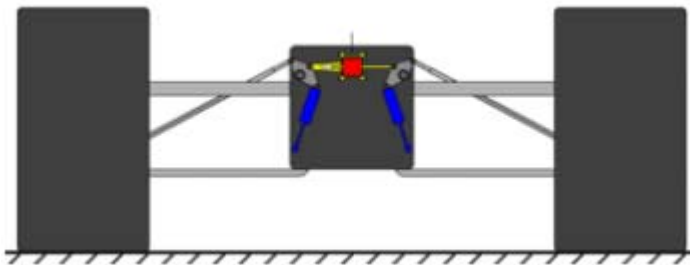
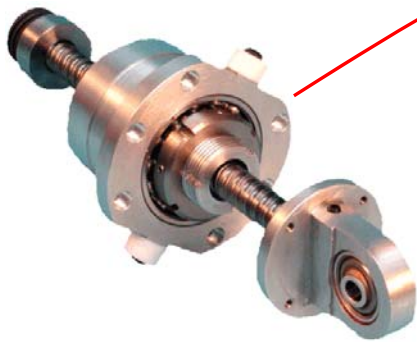
# Higher-Order $(\alpha, \beta)$ elements



# Higher-Order ( $\alpha, \beta$ ) elements



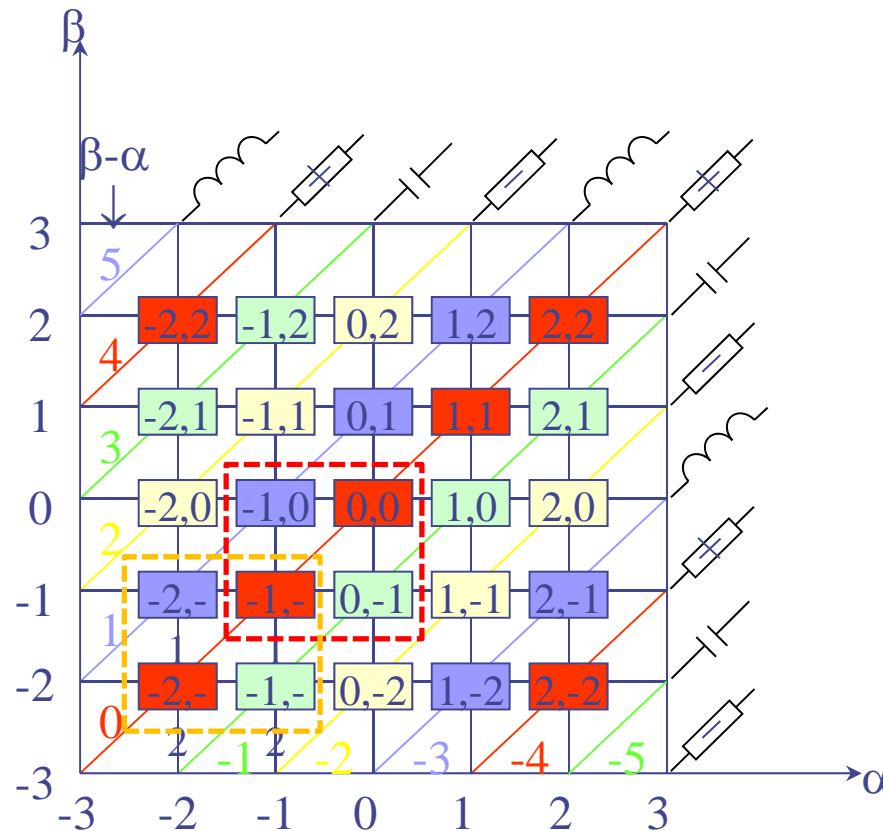
Inerter J-Dampers in Formula One



# Higher-Order $(\alpha, \beta)$ elements

Other role of Higher-Order Elements:

## ***Starting Point of Universal Modeling***



# Emulating Higher-Order ( $\alpha, \beta$ ) elements

**Why** to emulate Higher-Order Elements?

***Starting Point of emulating anything***

**How** to emulate Higher-Order Elements?

Universality

Simplicity

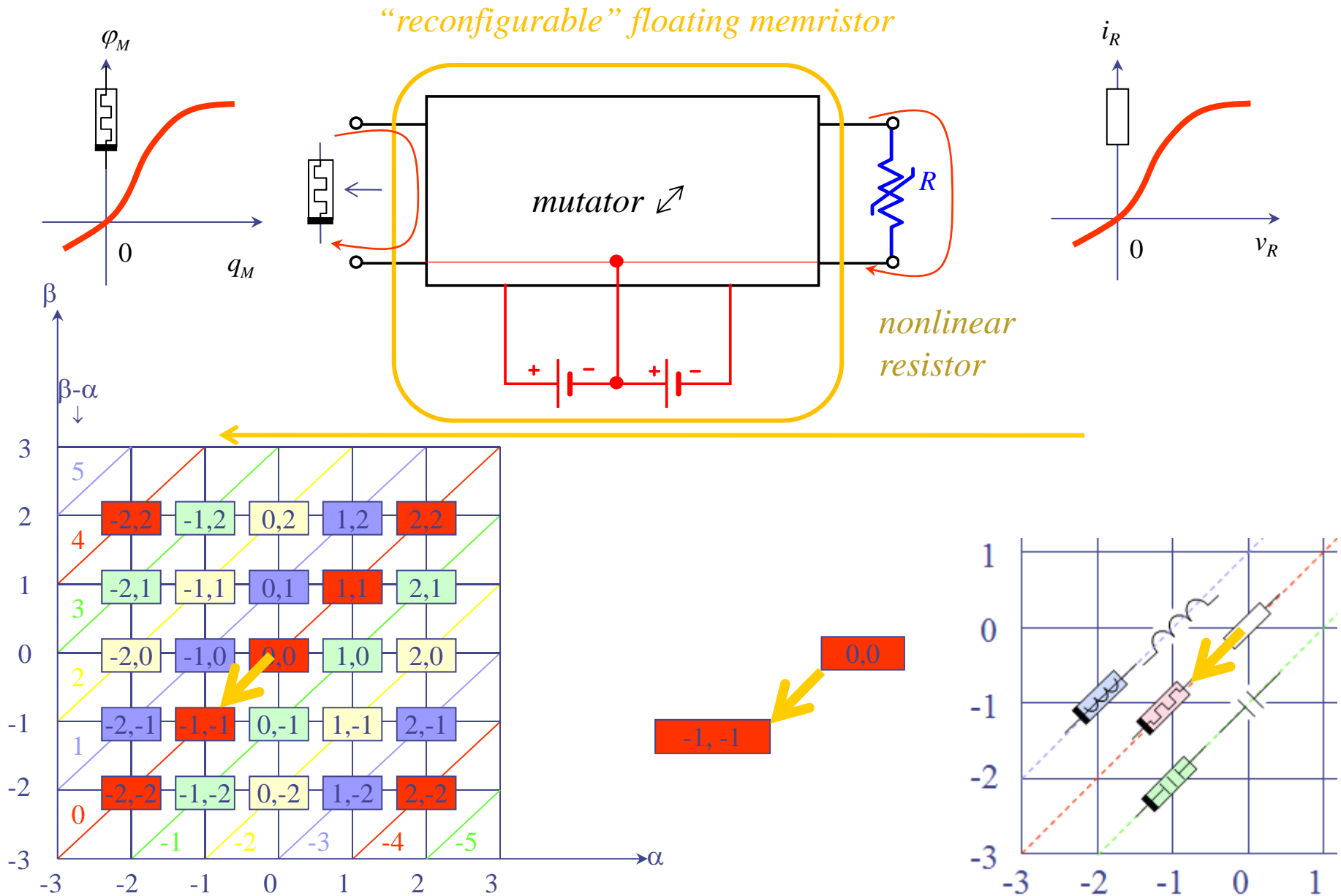
True floating component emulation

...

***Mutator Approach***



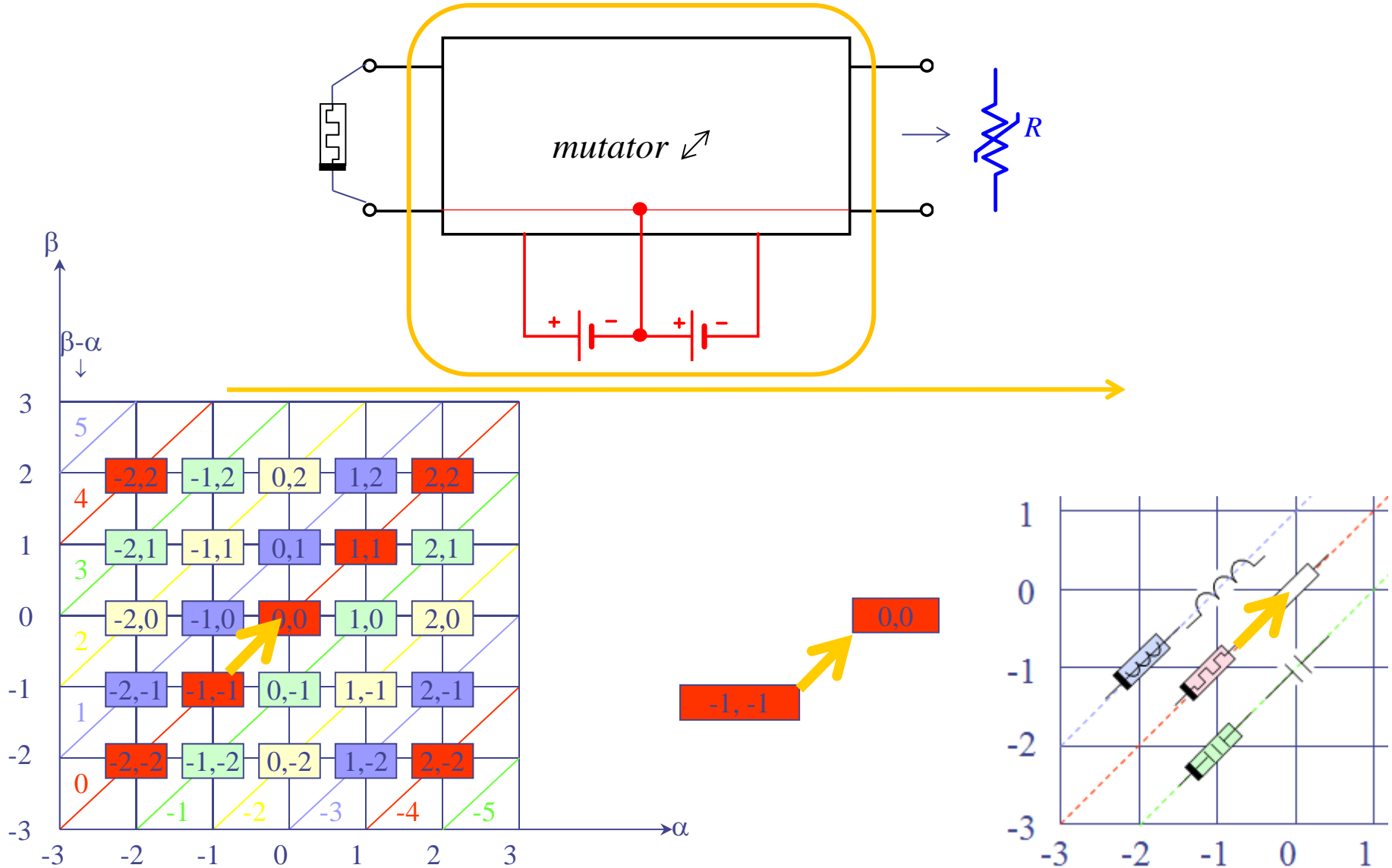
# Mutator approach





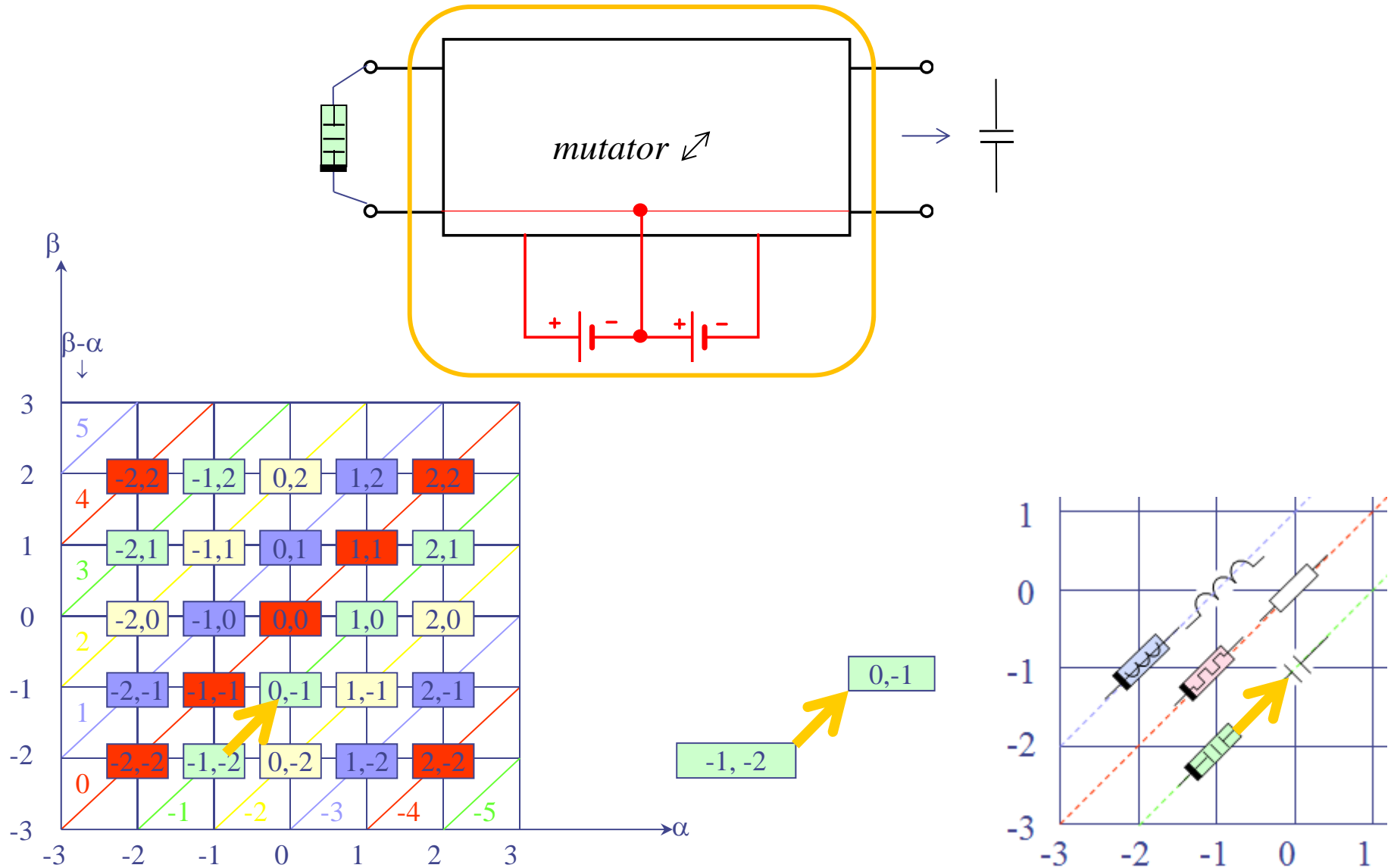
# Mutator approach

## Bi-directionality



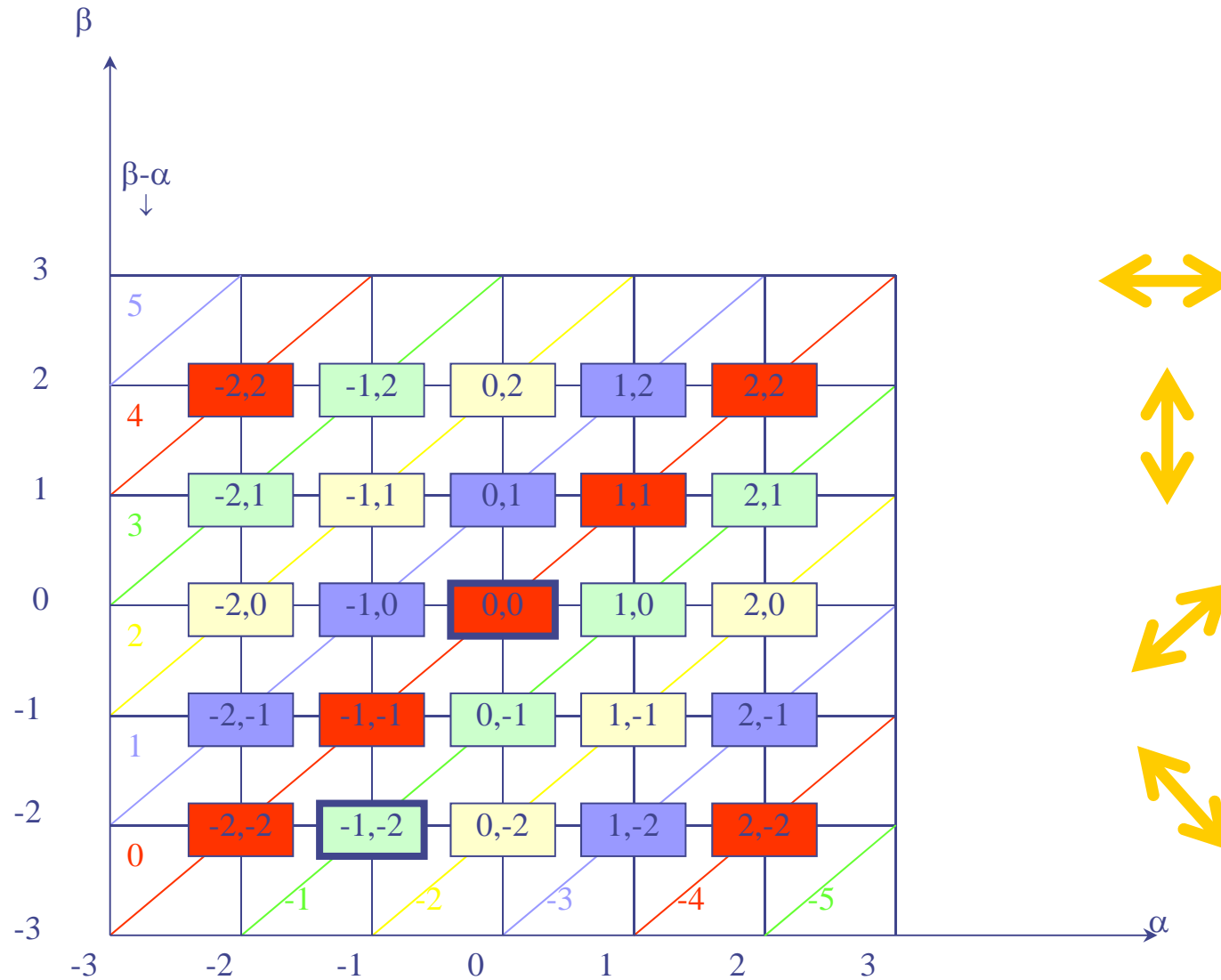
# Mutator approach

## Invariance



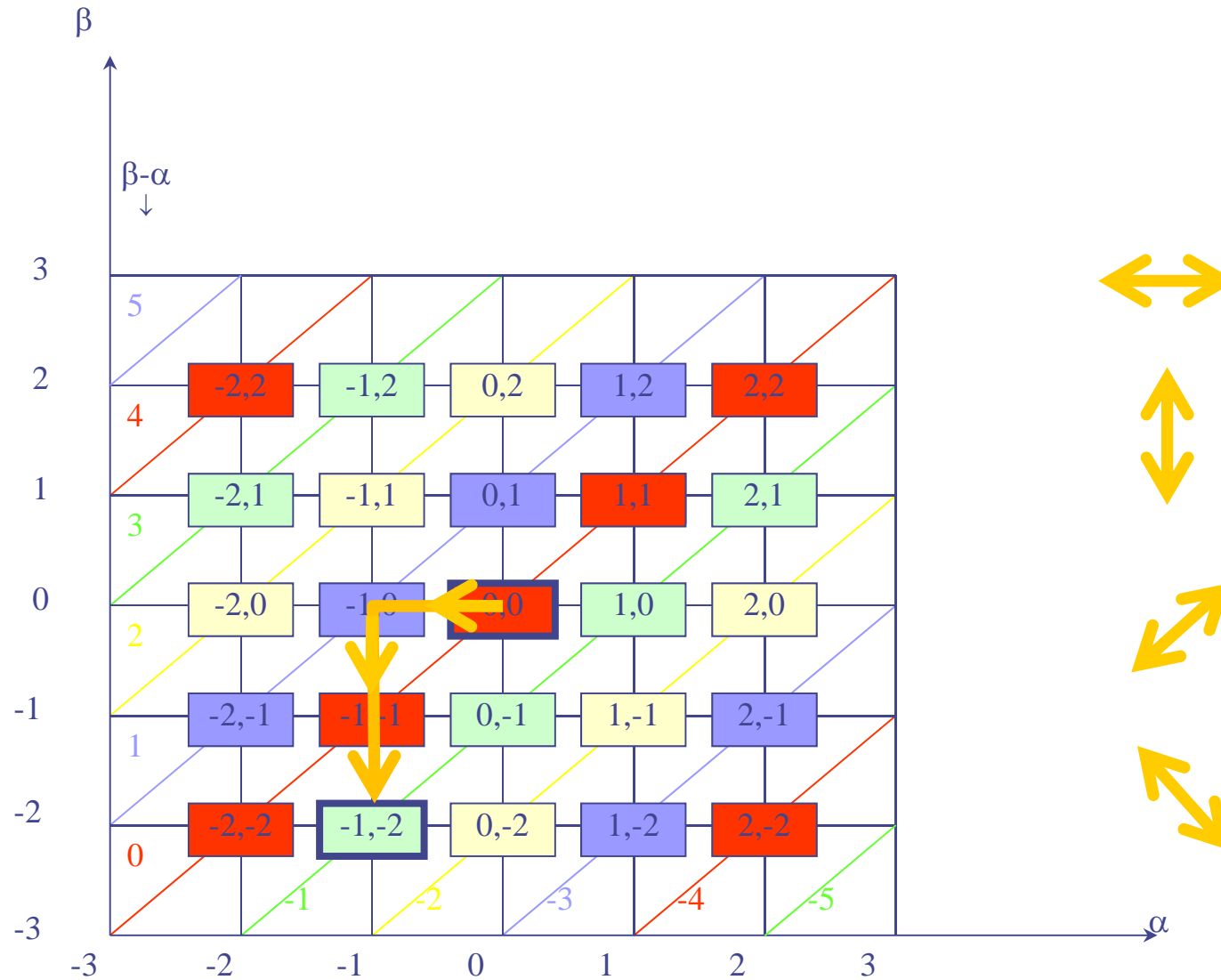
# Mutator approach

*INCREMENTAL MUTATORS for transforming elements in four directions*



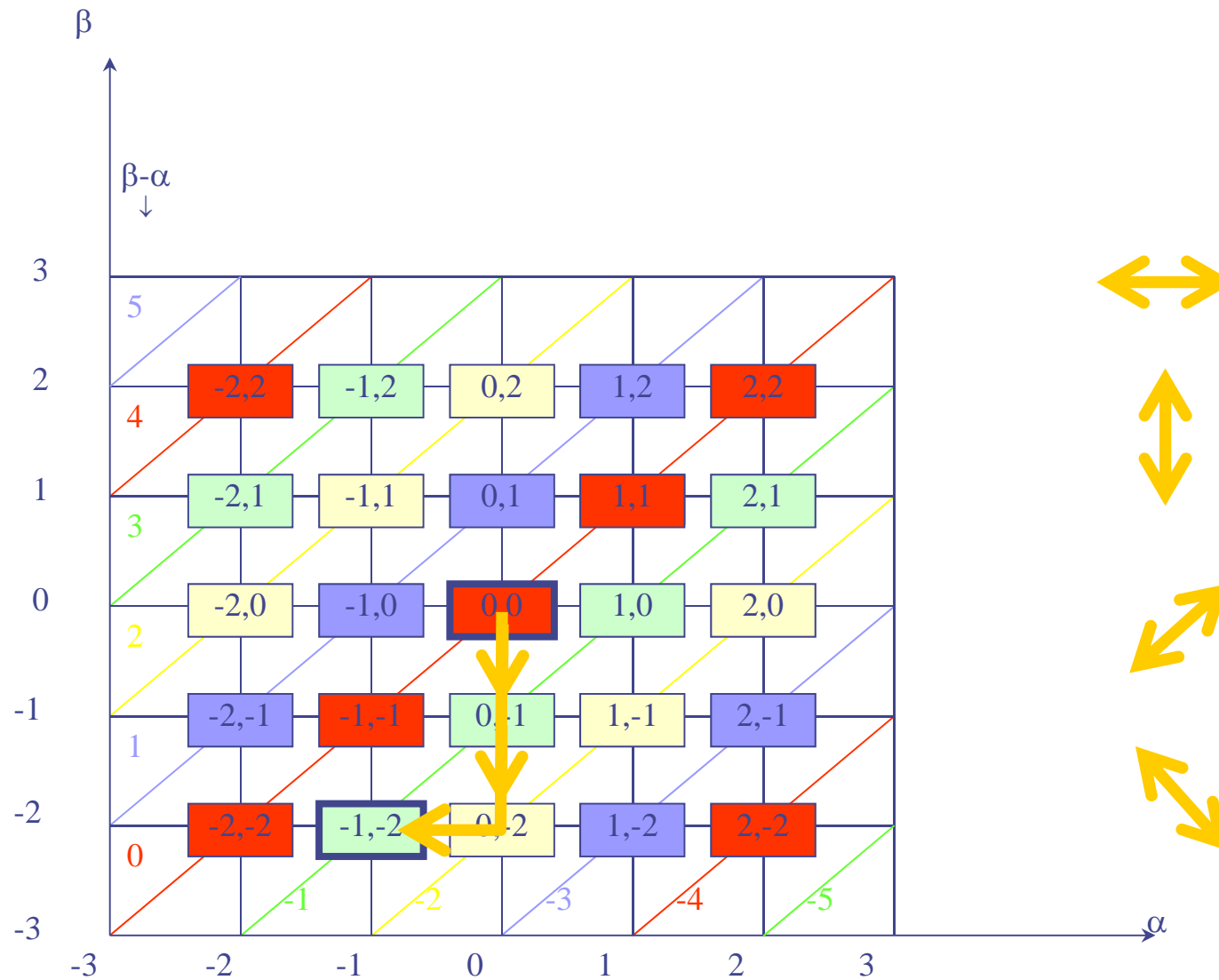
# Mutator approach

*INCREMENTAL MUTATORS for transforming elements in four directions*



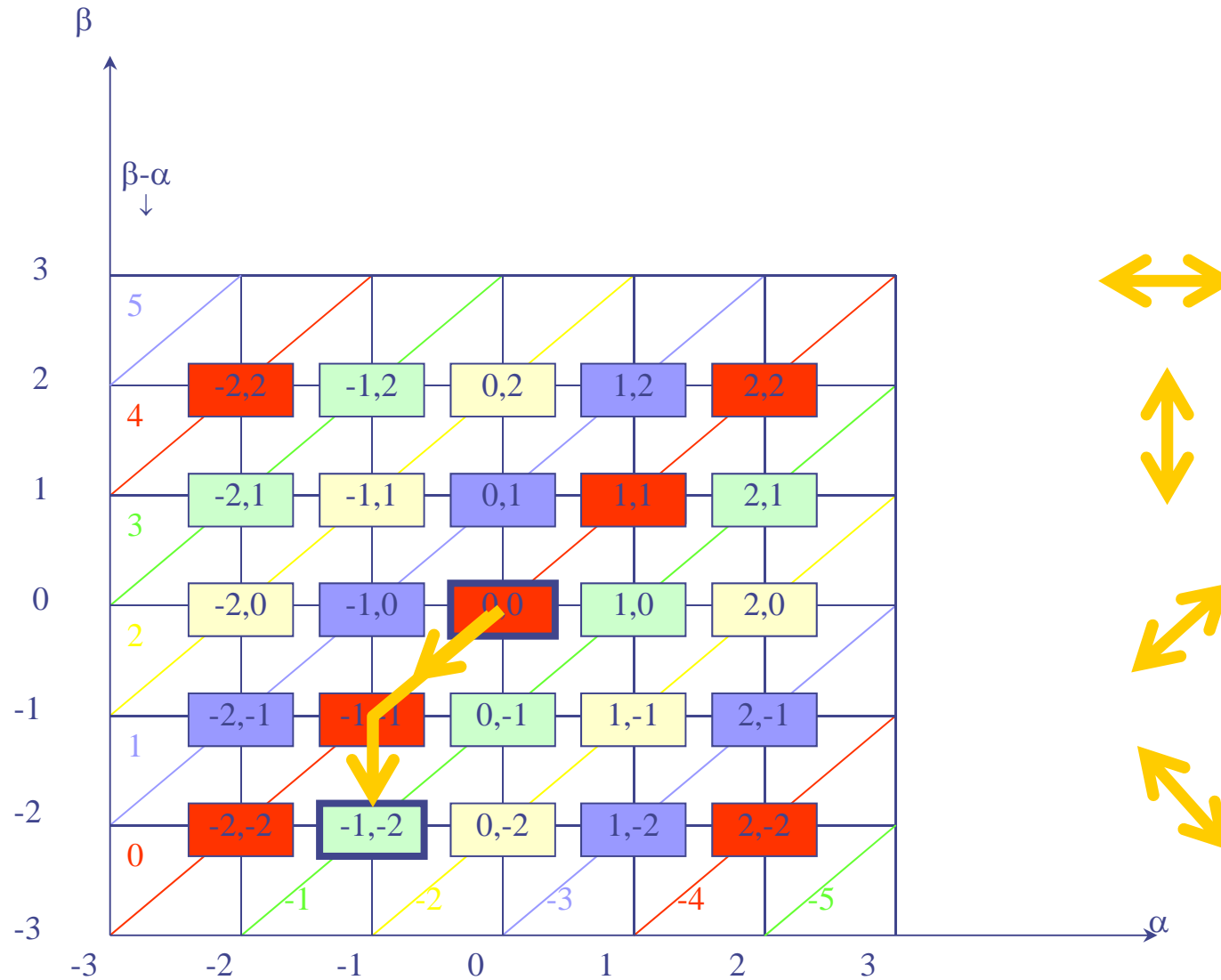
# Mutator approach

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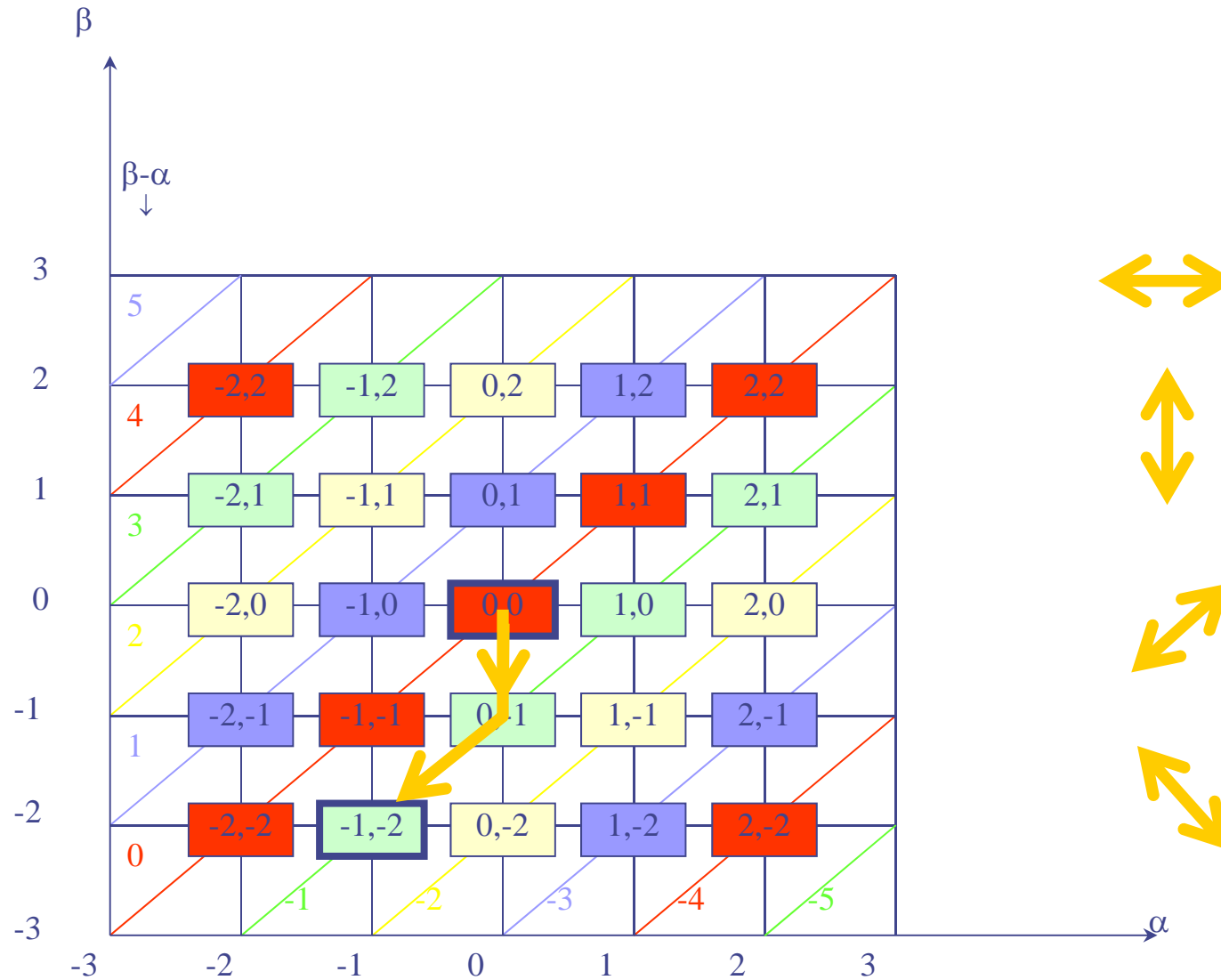
# Mutator approach

*INCREMENTAL MUTATORS for transforming elements in four directions*



# Mutator approach

*INCREMENTAL MUTATORS for transforming elements in four directions*





# Mutator approach

type	symbol	implementation using controlled sources	
		realization 1	realization 2
1			

## $[a, b]$ transformation in the table

$[\pm 1, 0]$	$\longleftrightarrow$
$[0, \pm 1]$	$\updownarrow$
$[\pm 1, \pm 1]$	$\nearrow$
$[\pm 1, \mp 1]$	$\nwarrow$

## 8 incremental mutators

They are implemented via controlled sources of integrating (-1), differentiating (1) and proportional (0) types.

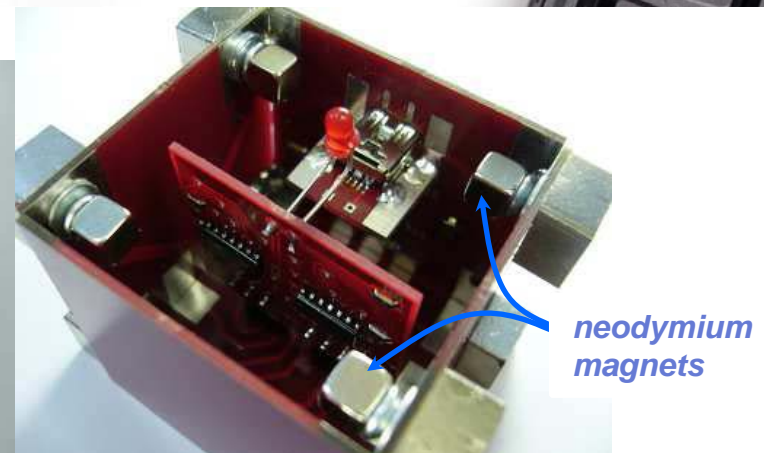
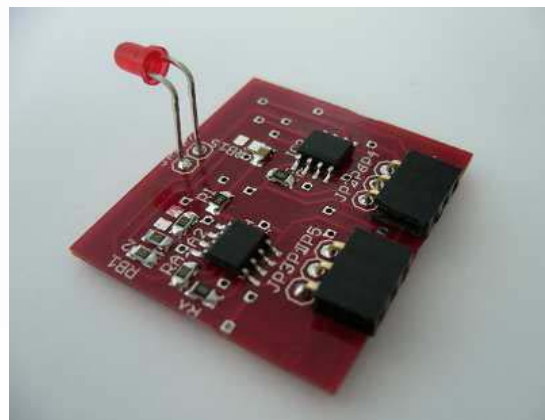
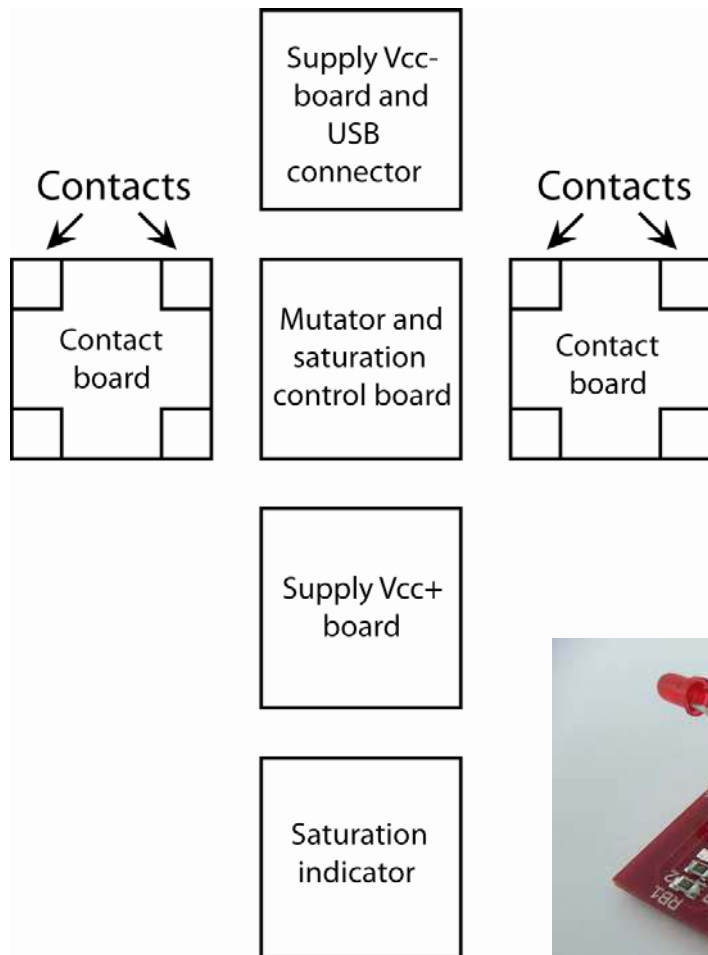
# Hardware implementation

Correctly designed mutator can transform nonlinear resistor into arbitrary HOE, preserving the shape of the constitutive relation.

*Good choice for emulating HOEs with all important fingerprints.*

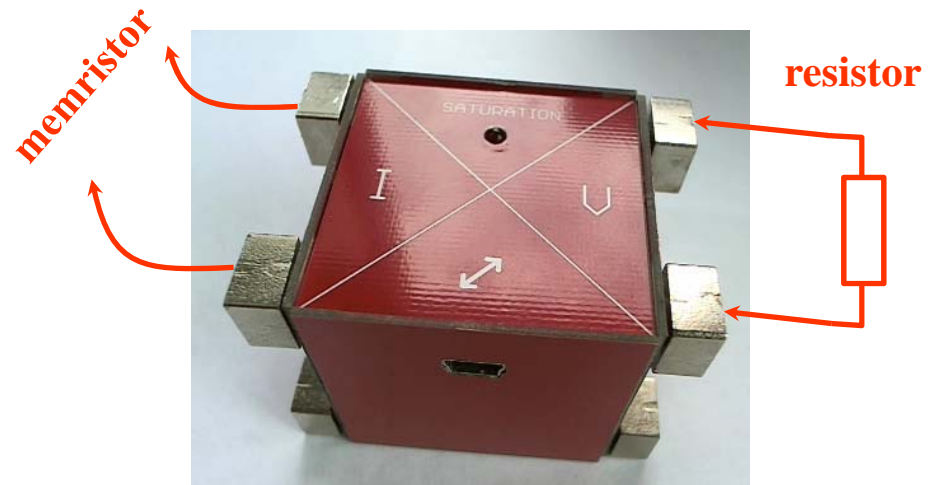
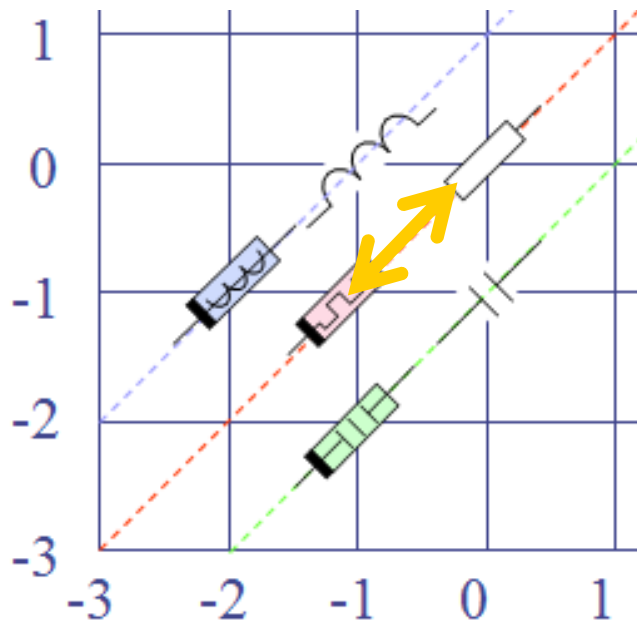


# Hardware implementation



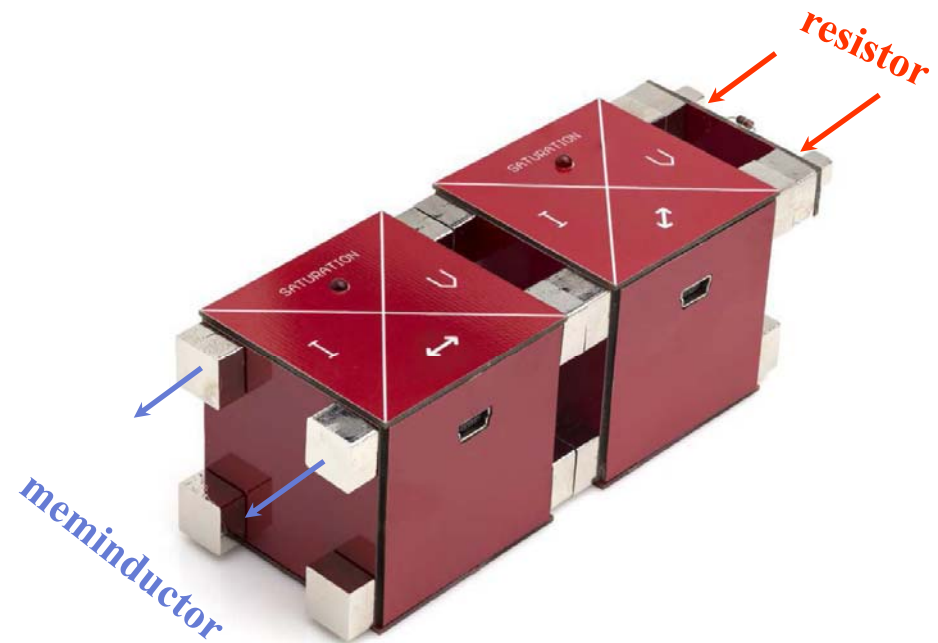
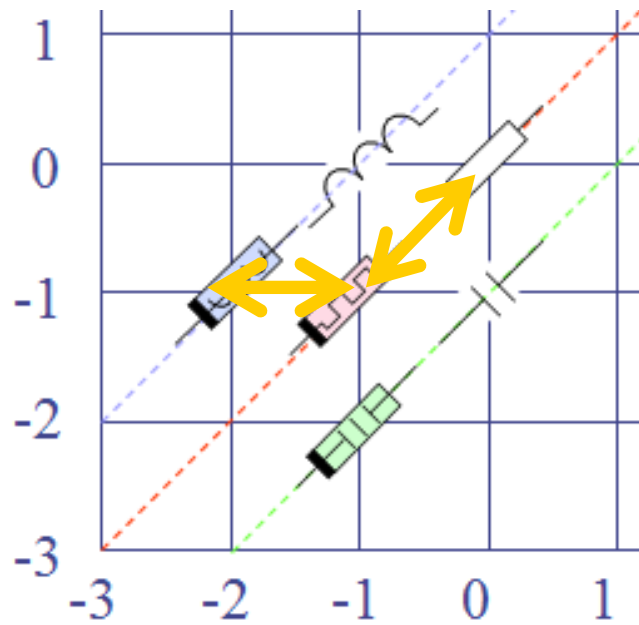
# Hardware implementation

Implementing floating **memristor** from nonlinear resistor



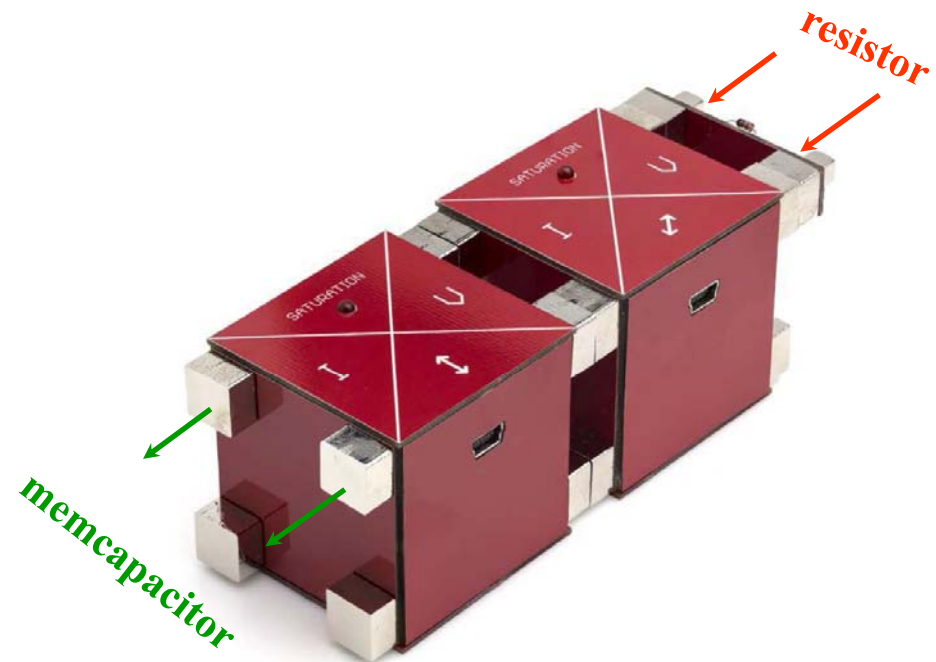
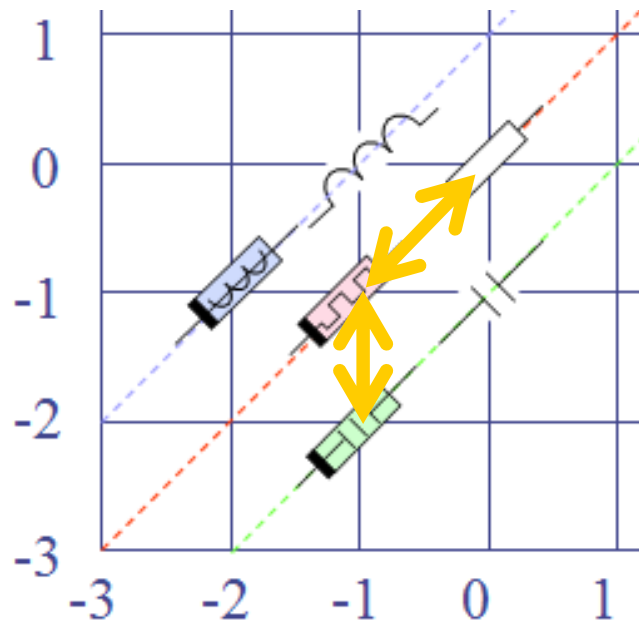
# Hardware implementation

Implementing floating *meminductor* from nonlinear resistor



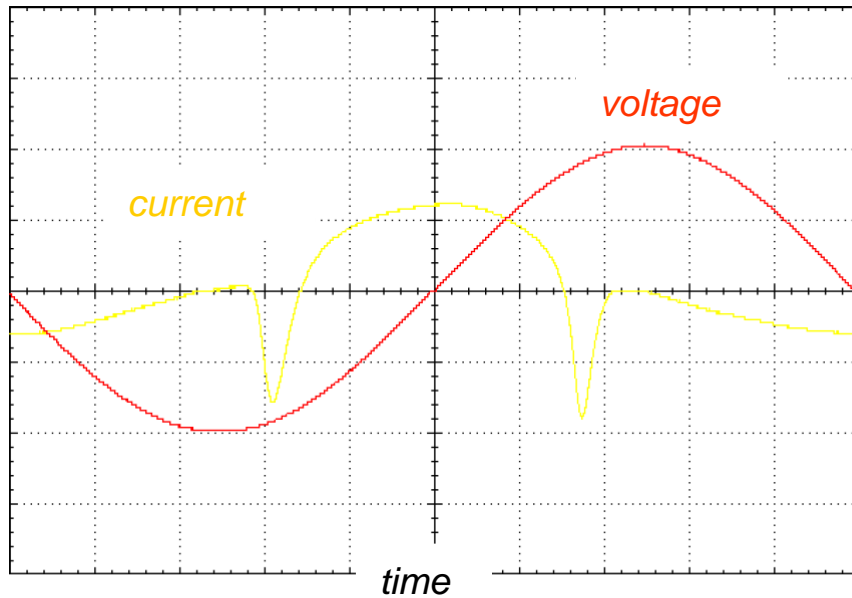
# Hardware implementation

Implementing floating **memcapacitor** from nonlinear resistor

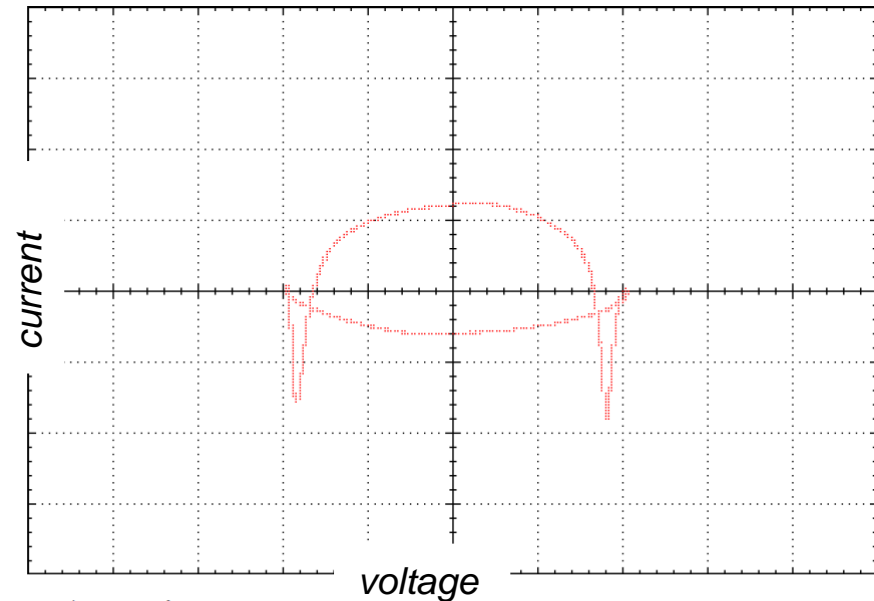


# Hardware implementation

## Implementing floating memcapacitor from nonlinear resistor



X/T režim  
CH1: 1 ms/div, 1V/div  
CH2: 1 ms/div, 100  $\mu$ A/div  
X1: - Y1: -  
X2: - Y2: -  
 $\Delta$ X: -  $\Delta$ Y: -

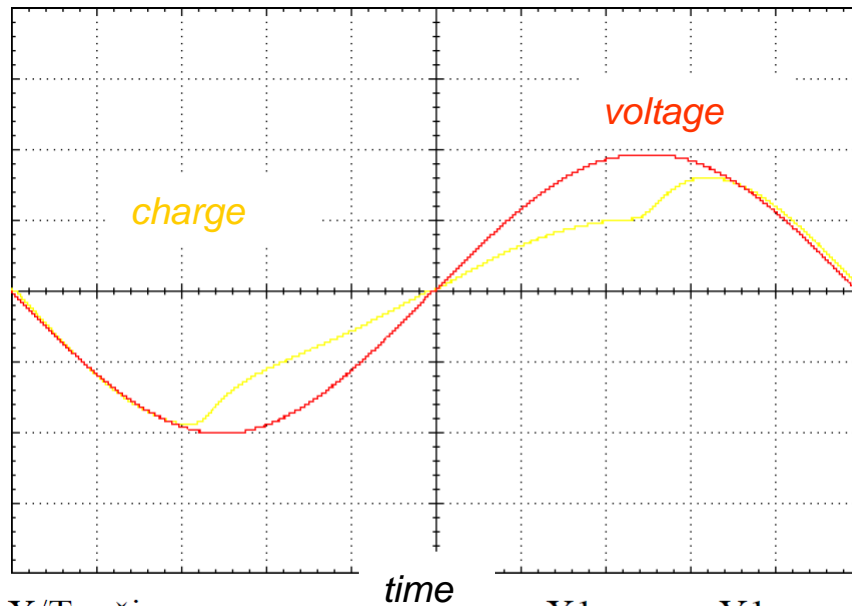


Y/X režim  
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 $\Delta$ X: -  $\Delta$ Y: -



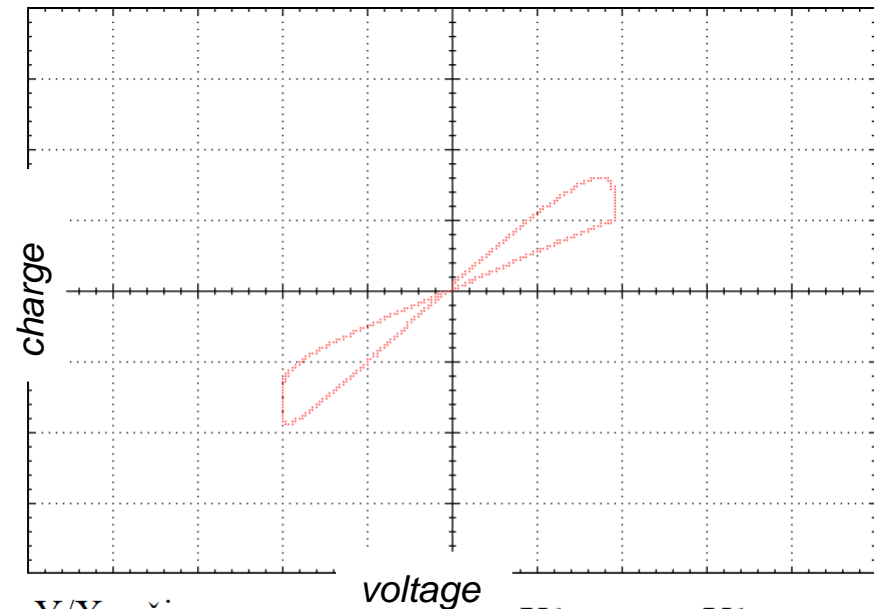
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## Instead of Conclusions

***Exact researching the theoretical circuit principles requires:***

***Good models for***  
***Good simulation tools and***  
***Good tools for experimental work***

