Draw intersecting positive feedback loops for all bistable and monostable networks
January 2015

▶ Initializations

▶ To execute before proceeding

▶ Comment

Hypothesis 1: two PF loops, one of them is competition loop, S to R interesecting edge, competed species not on the edge.

Hypothesis 2: (?with two competing futile cycles) two PF loops, one of them is competition loop, S to R interesecting edge, substrate (?after intermediate complex one species is transformed into another species) not on the edge.

▼ Bistable networks

All 8 bistable networks meet the condition in hypothesis 2; network 1, 2, 3, 5, 7, 8 meet condition in hypothesis 1.

▼ Network 1

Consider the network
A+B< -> C
D+B->E ->A+F
A->D
F->B

The stoichiometric matrix A is:

> $A := Transpose(Matrix([[-1,-1, 1, 0, 0, 0],-[-1,-1, 1, 0, 0, 0], [0,-1, 0,-1, 1, 0],$

[1, 0, 0, 0, -1, 1], [-1, 0, 0, 1, 0, 0], [0, 1, 0, 0, 0, -1]]));

$$A := \begin{bmatrix} -1 & 1 & 0 & 1 & -1 & 0 \\ -1 & 1 & -1 & 0 & 0 & 1 \\ 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 1 & 0 \\ 0 & 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & -1 \end{bmatrix} \tag{4.1.1}$$

Step 1.
Create the DSR-graph and find if there is a positive feedback loop through the competition.

> $mylabels := ["A", "B", "C", "D", "E", "F", seq(R_i, i = 1..6)]:$

> $findedgesDSR(mylabels, A)$

$$\{[["A", R_1], 1], [["A", R_5], 1], [["B", R_1], 1], [["B", R_3], 1], [["C", R_2], 1], [["D", R_3], 1], [["E", R_4], 1], [["F", R_6], 1], [[R_1, "A"], -1], [[R_1, "B"], -1], [[R_1, "C"], 1], [[R_2, "A"], 1], [[R_2, "B"], 1], [[R_2, "C"], -1], [[R_3, "B"], -1], [[R_3, "D"], -1], [[R_3, "E"], 1], [[R_4, "A"], 1], [[R_4, "E"], -1], [[R_4, "F"], 1], [[R_5, "A"], -1], [[R_5, "D"], 1], [[R_6, "B"], 1], [[R_6, "F"], -1]\} \tag{4.1.2}$$

If one wants to draw the graph, then one does:

> $G := createDSRgraphsigned(mylabels, A, findZ(A)):$

>

Step 2

Injectivity test:

> $isinjective(A)$

$$0 \tag{4.1.3}$$

Because the answer is 0, we apply the next test.

> $isinjectiveextended(A)$

$$2 \tag{4.1.4}$$

Because the answer is 2, we classify the network as MULTISTATIONARY.

Step 3
For the networks that are multistationary, decide whether multistationarity can be attributed to competition, and find the positive feedback loops underlying multistationarity.

> $Z := findZ(A) : n := Dimension(A)[1] : m := Dimension(A)[2] : s := Rank(A) :$

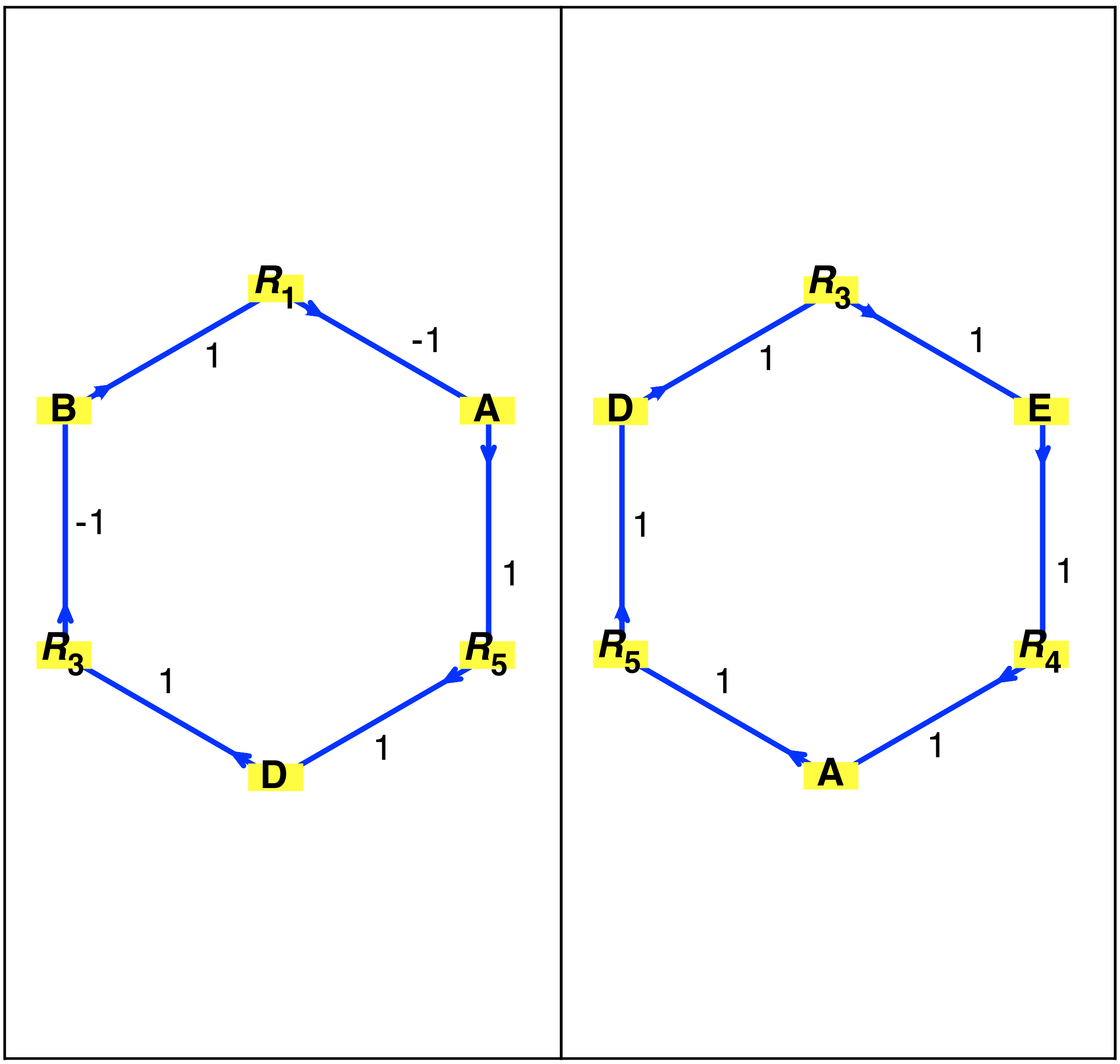
> $selected := findloops(\,)$

$$selected := [[[[R_1, S_1], -1], [[S_1, R_5], 1], [[R_5, S_4], 1], [[S_4, R_3], 1], [[R_3, S_2], -1], [[S_2, R_1], 1]], [[[R_3, S_5], 1], [[S_5, R_4], 1], [[R_4, S_1], 1], [[S_1, R_5], 1], [[R_5, S_4], 1], [[S_4, R_3], 1]]] \tag{4.1.5}$$

These are the positive feedback loops. You can draw the loops after giving a label to the species:

> $speciesord := [\text{"A"}, \text{"B"}, \text{"C"}, \text{"D"}, \text{"E"}, \text{"F"}] :$

> $drawloops(selected, speciesord)$



Network 2

A+B< -> C

D+B->G ->D+F
A->D
G->C
F->B

The stoichiometric matrix A is:

```
> A := Transpose(Matrix([[-1,-1, 1, 0, 0, 0],-[-1,-1, 1, 0, 0, 0], [0,-1, 0,-1, 0, 1], [0,
    0, 0, 1, 1,-1], [-1, 0, 0, 1, 0, 0], [0, 0, 1, 0, 0,-1], [0, 1, 0, 0,-1, 0]]));
```

$$A := \begin{bmatrix} -1 & 1 & 0 & 0 & -1 & 0 & 0 \\ -1 & 1 & -1 & 0 & 0 & 0 & 1 \\ 1 & -1 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & -1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & -1 \\ 0 & 0 & 1 & -1 & 0 & -1 & 0 \end{bmatrix} \quad \textbf{(4.2.1)}$$

Step 1.
Create the DSR-graph and find if there is a positive feedback loop through the competition.

```
> mylabels := ["A", "B", "C", "D", "F", "G", seq(R[i], i = 1 ..7)]:
> findedgesDSR(mylabels, A)
```

$\{[["A", R_1], 1], [["A", R_5], 1], [["B", R_1], 1], [["B", R_3], 1], [["C", R_2], 1], [["D", R_3], 1], [["F", R_7], 1], [["G", R_4], 1], [["G", R_6], 1], [[R_1, "A"], -1], [[R_1, "B"], -1], [[R_1, "C"], 1], [[R_2, "A"], 1], [[R_2, "B"], 1], [[R_2, "C"], -1], [[R_3, "B"], -1], [[R_3, "D"], -1], [[R_3, "G"], 1], [[R_4, "D"], 1], [[R_4, "F"], 1], [[R_4, "G"], -1], [[R_5, "A"], -1], [[R_5, "D"], 1], [[R_6, "C"], 1], [[R_6, "G"], -1], [[R_7, "B"], 1], [[R_7, "F"], -1]\}$ **(4.2.2)**

If one wants to draw the graph, then one does:

```
> G := createDSRgraphsigned(mylabels, A, findZ(A)) :
>
```

Step 2

Injectivity test:

```
> isinjective(A)
```

$$0 \quad \textbf{(4.2.3)}$$

Because the answer is 0, we apply the next test.

> $isinjectiveextended(A)$

$$0 \tag{4.2.4}$$

Because the answer is 0, you should use the toolbox.
The toolbox says YES, the network admits multiple steady states

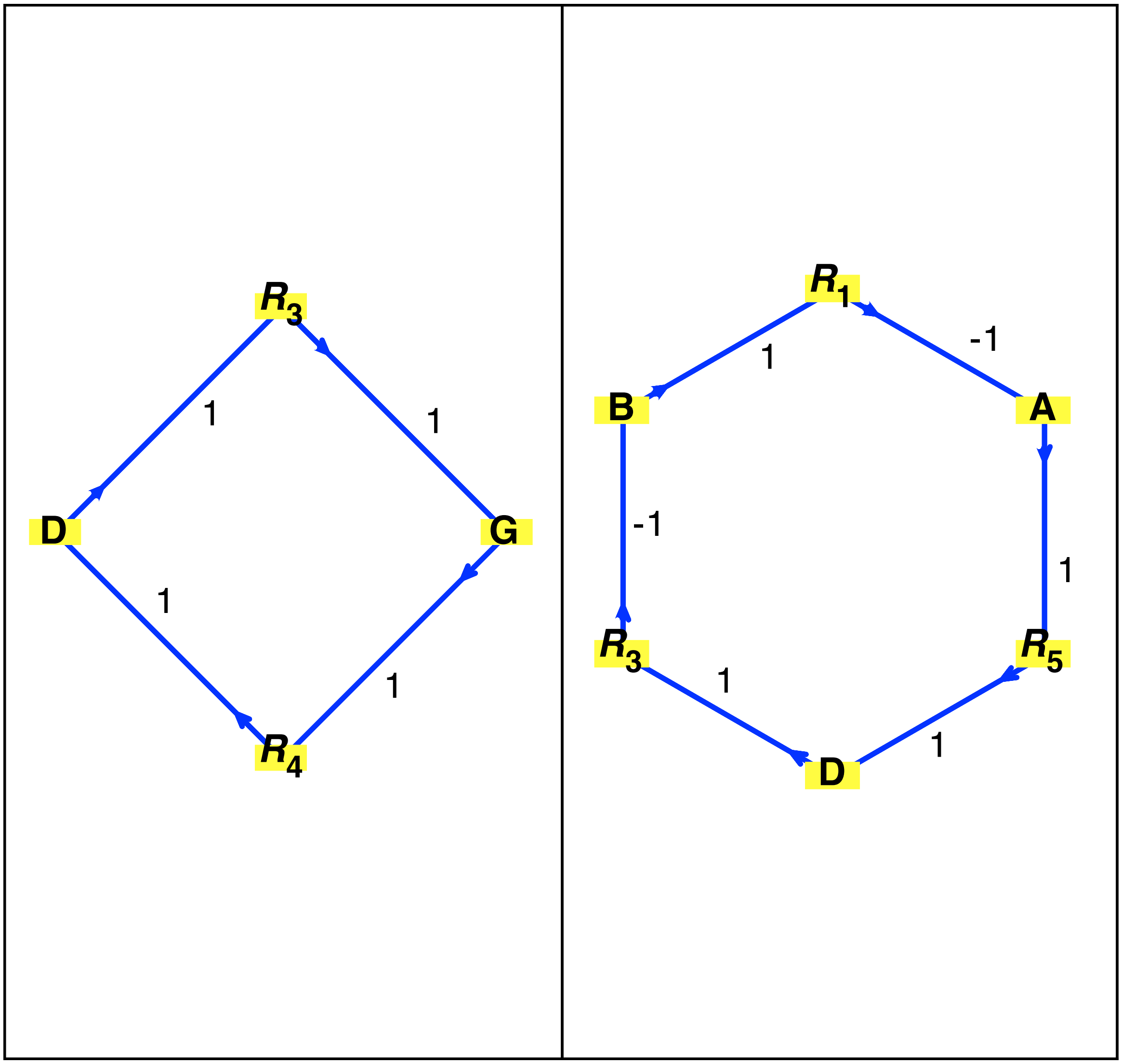
Step 3
We find the positive feedback loops.

> $Z := findZ(A) : n := Dimension(A)[1] : m := Dimension(A)[2] : s := Rank(A) :$
> $selected := findloops(\,)$

$$selected := [[[[R_3, S_6], 1], [[S_6, R_4], 1], [[R_4, S_4], 1], [[S_4, R_3], 1]], [[[R_1, S_1], -1], [[S_1, R_5], 1], [[R_5, S_4], 1], [[S_4, R_3], 1], [[R_3, S_2], -1], [[S_2, R_1], 1]]] \tag{4.2.5}$$

These are the positive feedback loops. You can draw the loops after giving a label to the species:

> $speciesord := ["A", "B", "C", "D", "F", "G"] :$
> $drawloops(selected, speciesord)$



Network 3

Consider the network
A+B< -> C
D+B->E ->A+F
A->D
F->B

The stoichiometric matrix A is:

```
> A := Transpose(Matrix([[-1,-1, 1, 0, 0, 0],-[-1,-1, 1, 0, 0, 0], [0,-1, 0,-1, 1, 0],
      [1, 0, 0, 0,-1, 1], [-1, 0, 0, 1, 0, 0], [0, 1, 0, 0, 0,-1]]));
```

(4.3.1)

$$A := \begin{bmatrix} -1 & 1 & 0 & 1 & -1 & 0 \\ -1 & 1 & -1 & 0 & 0 & 1 \\ 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 1 & 0 \\ 0 & 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & -1 \end{bmatrix} \tag{4.3.1}$$

Step 1.
Create the DSR-graph and find if there is a positive feedback loop through the competition.

> $mylabels := [\text{"A"}, \text{"B"}, \text{"C"}, \text{"D"}, \text{"E"}, \text{"F"}, seq(R_i, i = 1..6)]:$

> $findedgesDSR(mylabels, A)$

$$\{[[\text{"A"}, R_1], 1], [[\text{"A"}, R_5], 1], [[\text{"B"}, R_1], 1], [[\text{"B"}, R_3], 1], [[\text{"C"}, R_2], 1], [[\text{"D"}, R_3], 1], [[\text{"E"}, R_4], 1], [[\text{"F"}, R_6], 1], [[R_1, \text{"A"}], -1], [[R_1, \text{"B"}], -1], [[R_1, \text{"C"}], 1], [[R_2, \text{"A"}], 1], [[R_2, \text{"B"}], 1], [[R_2, \text{"C"}], -1], [[R_3, \text{"B"}], -1], [[R_3, \text{"D"}], -1], [[R_3, \text{"E"}], 1], [[R_4, \text{"A"}], 1], [[R_4, \text{"E"}], -1], [[R_4, \text{"F"}], 1], [[R_5, \text{"A"}], -1], [[R_5, \text{"D"}], 1], [[R_6, \text{"B"}], 1], [[R_6, \text{"F"}], -1]\} \tag{4.3.2}$$

If one wants to draw the graph, then one does:

> $G := createDSRgraphsigned(mylabels, A, findZ(A)):$

>

Step 2

Injectivity test:

> $isinjective(A)$

$$0 \tag{4.3.3}$$

Because the answer is 0, we apply the next test.

> $isinjectiveextended(A)$

$$2 \tag{4.3.4}$$

Because the answer is 2, we classify the network as MULTISTATIONARY.

Step 3
For the networks that are multistationary, decide whether multistationarity can be attributed to competition, and find the positive feedback loops underlying multistationarity.

> $Z := findZ(A) : n := Dimension(A)[1] : m := Dimension(A)[2] : s := Rank(A) :$

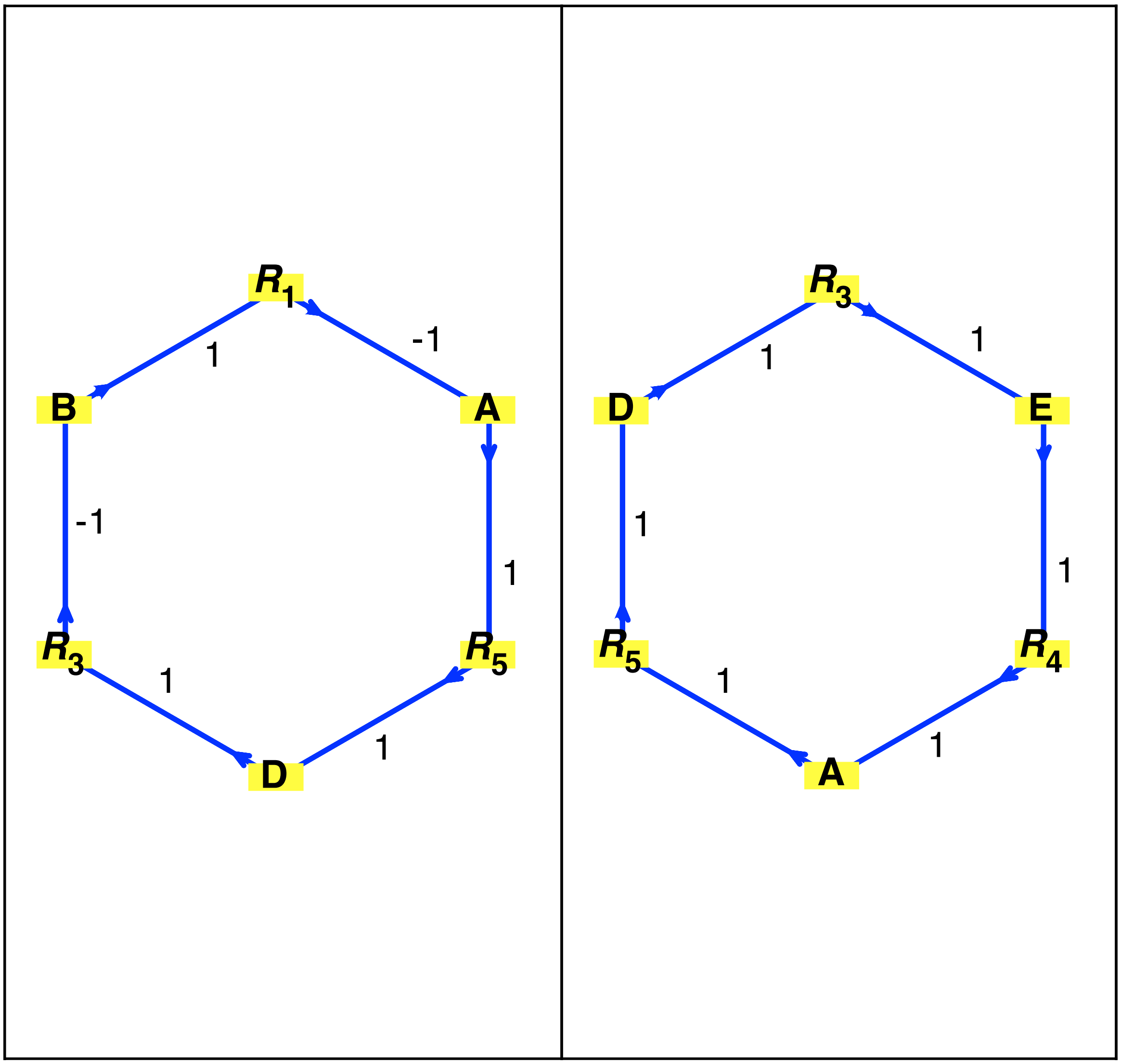
> $selected := findloops(\,)$

$selected := [[[[R_1, S_1], -1], [[S_1, R_5], 1], [[R_5, S_4], 1], [[S_4, R_3], 1], [[R_3, S_2], -1], [[S_2, R_1], 1]], [[[R_3, S_5], 1], [[S_5, R_4], 1], [[R_4, S_1], 1], [[S_1, R_5], 1], [[R_5, S_4], 1], [[S_4, R_3], 1]]]$ **(4.3.5)**

These are the positive feedback loops. You can draw the loops after giving a label to the species:

> $speciesord := [\text{"A"}, \text{"B"}, \text{"C"}, \text{"D"}, \text{"E"}, \text{"F"}] :$

> $drawloops(selected, speciesord)$



Network 4

$A + B \rightleftharpoons C \rightarrow \mathrm{D} + A$

$A + E \rightleftharpoons F \rightarrow G + A$
$B \rightleftharpoons E$
$\mathrm{D} \rightleftharpoons G$
$C \rightleftharpoons F$
$\mathrm{D} \rightarrow B$
$G \rightarrow E$

The stoichiometric matrix A is:

```
> A := Transpose(Matrix([[-1,-1, 1, 0, 0, 0, 0],-[-1,-1, 1, 0, 0, 0, 0], [1, 0,-1, 1, 0, 0,
      0], [-1, 0, 0, 0,-1, 1, 0],-[-1, 0, 0, 0,-1, 1, 0], [1, 0, 0, 0, 0,-1, 1], [0,-1, 0, 0, 1,
      0, 0],-[0,-1, 0, 0, 1, 0, 0], [0, 0, 0,-1, 0, 0, 1],-[0, 0, 0,-1, 0, 0, 1], [0, 0,-1, 0, 0,
      1, 0],-[0, 0,-1, 0, 0, 1, 0], [0, 1, 0,-1, 0, 0, 0], [0, 0, 0, 0, 1, 0,-1]]));
```

$$A := \begin{bmatrix} -1 & 1 & 1 & -1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 1 & 0 & 0 & 0 & 0 & -1 & 1 & 0 & 0 & 0 & 0 & 1 & 0 \\ 1 & -1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & -1 & 1 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 & 1 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & -1 & -1 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & -1 \end{bmatrix} \quad \textbf{(4.4.1)}$$

```
>
```

Create the DSR-graph and find if there is a positive feedback loop through the competition.

```
> mylabels := ["A", "B", "C", "D", "E", "F", "G", seq(R[i], i = 1 ..14)]:
> findedgesDSR(mylabels, A)
```

$$\{[["A", R_1], 1], [["A", R_4], 1], [["B", R_1], 1], [["B", R_7], 1], [["C", R_2], 1], [["C", R_3], 1], [["C", R_{11}], 1], [["D", R_9], 1], [["D", R_{13}], 1], [["E", R_4], 1], [["E", R_8], 1], [["F", R_5], 1], [["F", R_6], 1], [["F", R_{12}], 1], [["G", R_{10}], 1], [["G", R_{14}], 1], [[R_1, "A"], -1], [[R_1, "B"], -1], [[R_1, "C"], 1], [[R_2, "A"], 1], [[R_2, "B"], 1], [[R_2, "C"], -1], [[R_3, "A"], 1], [[R_3, "C"], -1], [[R_3, "D"], 1], [[R_4, "A"], -1], [[R_4, "E"], -1], [[R_4, "F"], 1], [[R_5, "A"], 1], [[R_5, "E"], 1], [[R_5, "F"], -1], [[R_6, "A"], 1], [[R_6, "F"], -1], [[R_6, "G"], 1], [[R_7, "B"], -1], [[R_7, "E"], 1], [[R_8, "B"], 1], [[R_8, "E"], -1], [[R_9, "D"], -1], [[R_9, "G"], 1], [[R_{10}, "D"], 1], [[R_{10}, "G"], -1], [[R_{11}, "C"], -1], [[R_{11}, "F"], 1], [[R_{12}, "C"], 1], [[R_{12}, "F"], -1], [[R_{13}, "B"], 1], [[R_{13}, "D"], -1], [[R_{14}, "E"], 1], [[R_{14}, "G"], -1]\} \quad \textbf{(4.4.2)}$$

```
>
```

check injectivity

> $isinjective(A)$

$$0 \tag{4.4.3}$$

> $isinjectiveextended(A)$

$$0 \tag{4.4.4}$$

>

Draw the loops

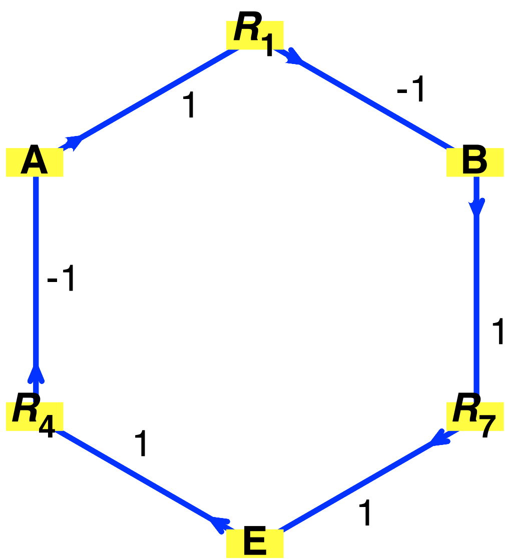
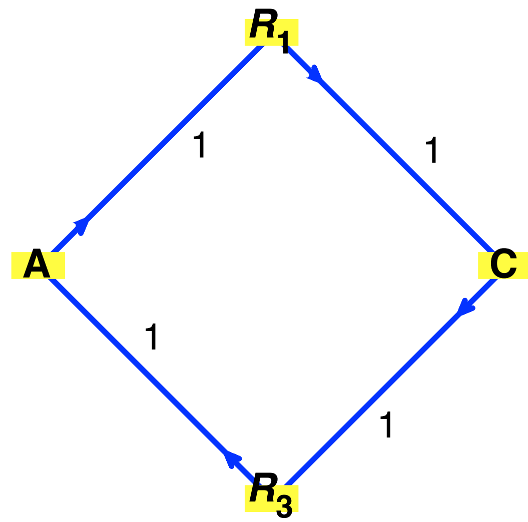
> $Z := findZ(A) : n := Dimension(A)[1] : m := Dimension(A)[2] : s := Rank(A) :$

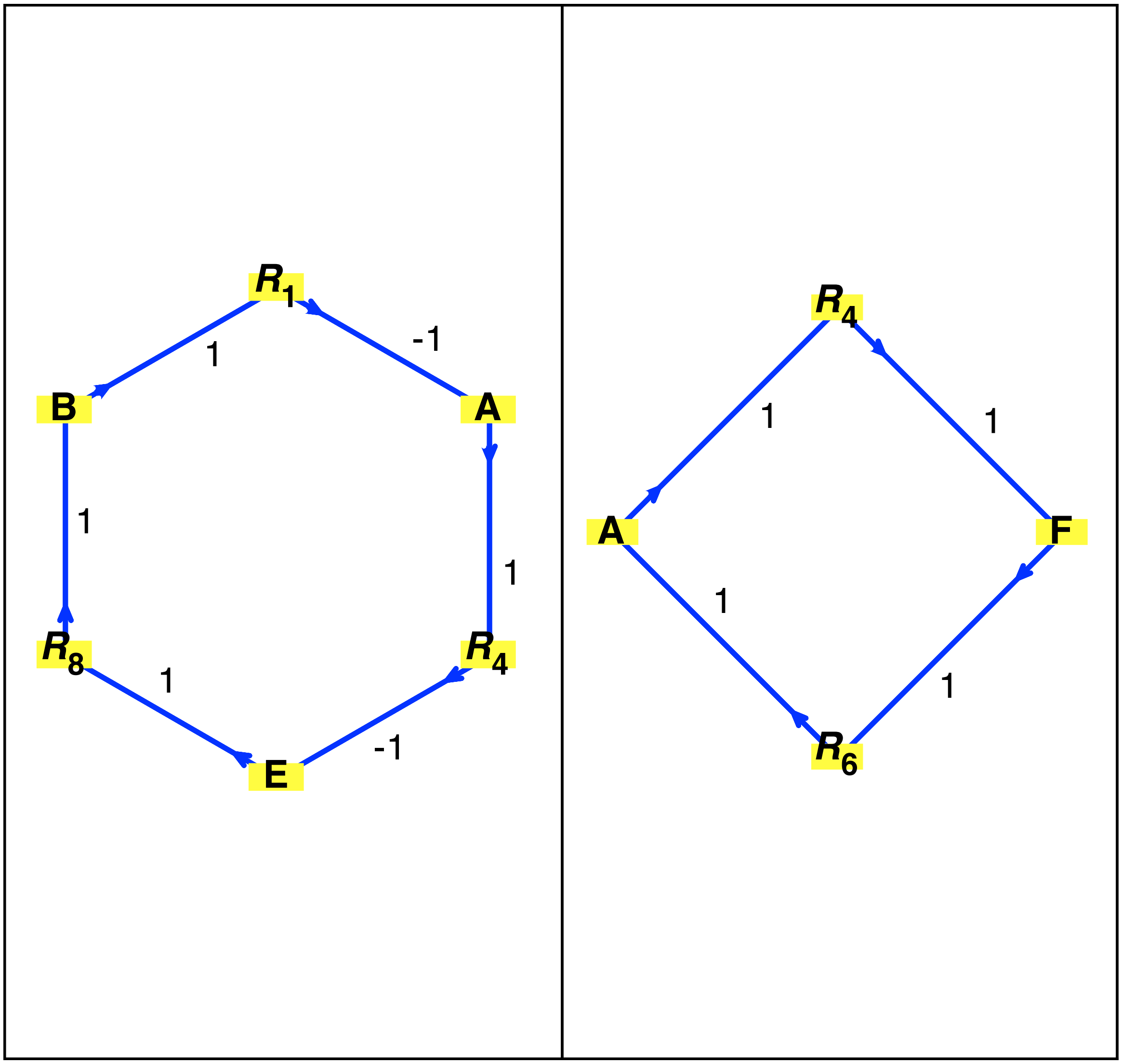
> $selected := findloops(\,)$

$$selected := [[[[R_1, S_2], -1], [[S_2, R_7], 1], [[R_7, S_5], 1], [[S_5, R_4], 1], [[R_4, S_1], -1], [[S_1, R_1], 1]], [[[R_1, S_3], 1], [[S_3, R_3], 1], [[R_3, S_1], 1], [[S_1, R_1], 1]], [[[R_1, S_1], -1], [[S_1, R_4], 1], [[R_4, S_5], -1], [[S_5, R_8], 1], [[R_8, S_2], 1], [[S_2, R_1], 1]], [[[R_4, S_6], 1], [[S_6, R_6], 1], [[R_6, S_1], 1], [[S_1, R_4], 1]]] \tag{4.4.5}$$

> $speciesord := [\text{"A"}, \text{"B"}, \text{"C"}, \text{"D"}, \text{"E"}, \text{"F"}, \text{"G"}] :$

> $drawloops(selected, speciesord)$

R_1 A B R_4 R_7 E 1 -1 -1 1 1 1	R_1 A C R_3 1 1 1 1



>

Network 5

$A + B \rightleftharpoons C \rightarrow \mathrm{D} + B$
$A + E \rightleftharpoons F \rightarrow \mathrm{D} + E$
$B \rightleftharpoons E$
$C \rightleftharpoons F$
$\mathrm{D} \rightarrow A$

The stoichiometric matrix A is:

```
> A := Transpose(Matrix([[-1,-1,1,0,0,0],-[-1,-1,1,0,0,0],[0,1,-1,1,0,0],[
    -1,0,0,0,-1,1],-[-1,0,0,0,-1,1],[0,0,0,1,1,-1],[0,-1,0,0,1,0],-[0,-1,
    0,0,1,0],[0,0,-1,0,0,1],-[0,0,-1,0,0,1],[1,0,0,-1,0,0]]));
```

$$A := \begin{bmatrix} -1 & 1 & 0 & -1 & 1 & 0 & 0 & 0 & 0 & 0 & 1 \\ -1 & 1 & 1 & 0 & 0 & 0 & -1 & 1 & 0 & 0 & 0 \\ 1 & -1 & -1 & 0 & 0 & 0 & 0 & 0 & -1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & -1 & 1 & 1 & 1 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & -1 & -1 & 0 & 0 & 1 & -1 & 0 \end{bmatrix} \quad \textbf{(4.5.1)}$$

>

Create the DSR-graph and find if there is a positive feedback loop through the competition.

```
> mylabels := ["A", "B", "C", "D", "E", "F", seq(R[i], i = 1..11)] :
> findedgesDSR(mylabels, A)
```

$\{[["A", R_1], 1], [["A", R_4], 1], [["B", R_1], 1], [["B", R_7], 1], [["C", R_2], 1], [["C", R_3], 1], [["C", R_9], 1], [["D", R_{11}], 1], [["E", R_4], 1], [["E", R_8], 1], [["F", R_5], 1], [["F", R_6], 1], [["F", R_{10}], 1], [[R_1, "A"], -1], [[R_1, "B"], -1], [[R_1, "C"], 1], [[R_2, "A"], 1], [[R_2, "B"], 1], [[R_2, "C"], -1], [[R_3, "B"], 1], [[R_3, "C"], -1], [[R_3, "D"], 1], [[R_4, "A"], -1], [[R_4, "E"], -1], [[R_4, "F"], 1], [[R_5, "A"], 1], [[R_5, "E"], 1], [[R_5, "F"], -1], [[R_6, "D"], 1], [[R_6, "E"], 1], [[R_6, "F"], -1], [[R_7, "B"], -1], [[R_7, "E"], 1], [[R_8, "B"], 1], [[R_8, "E"], -1], [[R_9, "C"], -1], [[R_9, "F"], 1], [[R_{10}, "C"], 1], [[R_{10}, "F"], -1], [[R_{11}, "A"], 1], [[R_{11}, "D"], -1]\}$ **(4.5.2)**

>

check injectivity

```
> isinjective(A)
```

$$0 \quad \textbf{(4.5.3)}$$

```
> isinjectiveextended(A)
```

$$0 \quad \textbf{(4.5.4)}$$

>

Draw the loops

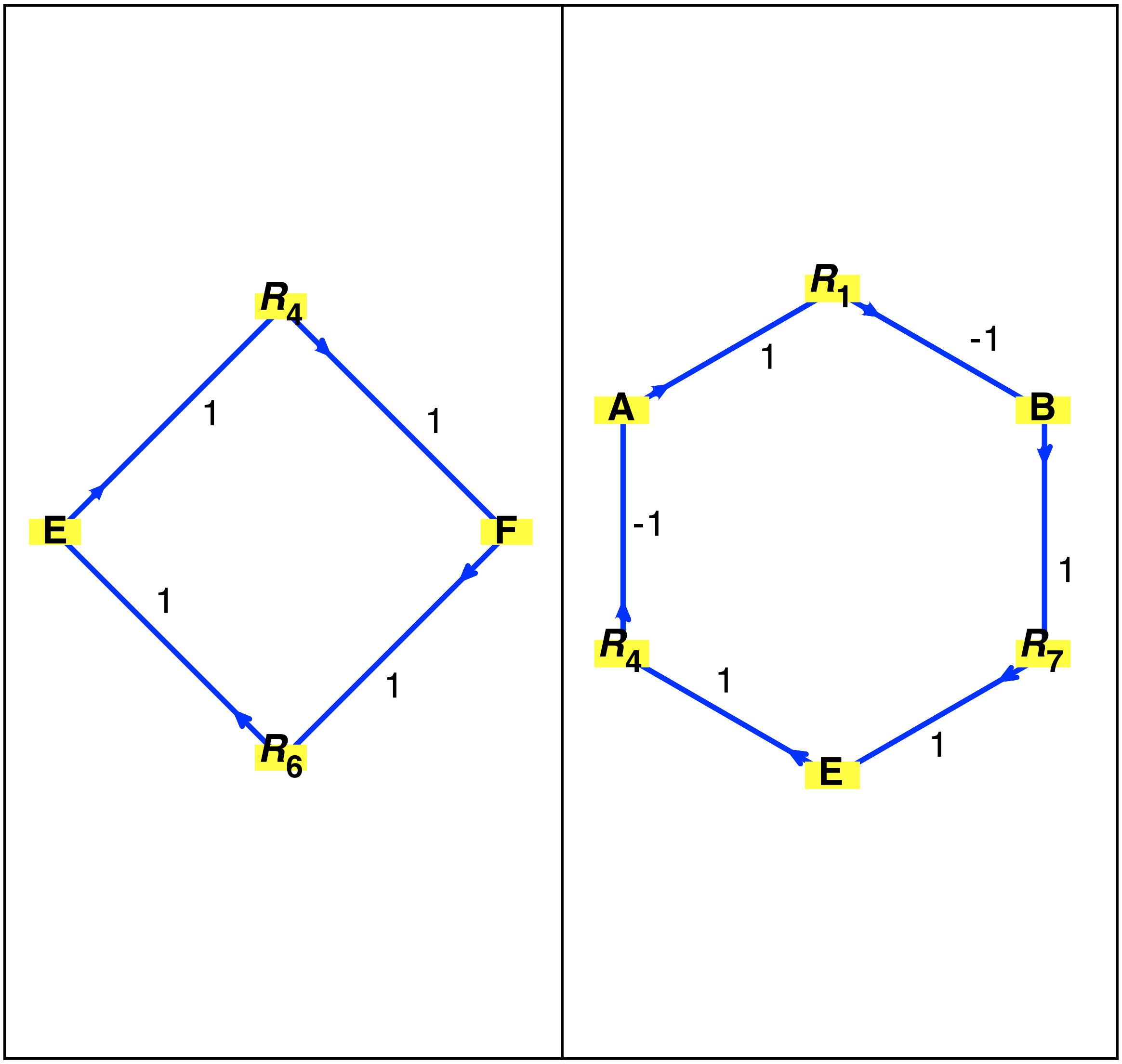
```
> Z := findZ(A) : n := Dimension(A)[1] : m := Dimension(A)[2] : s := Rank(A) :
> selected := findloops( )
```

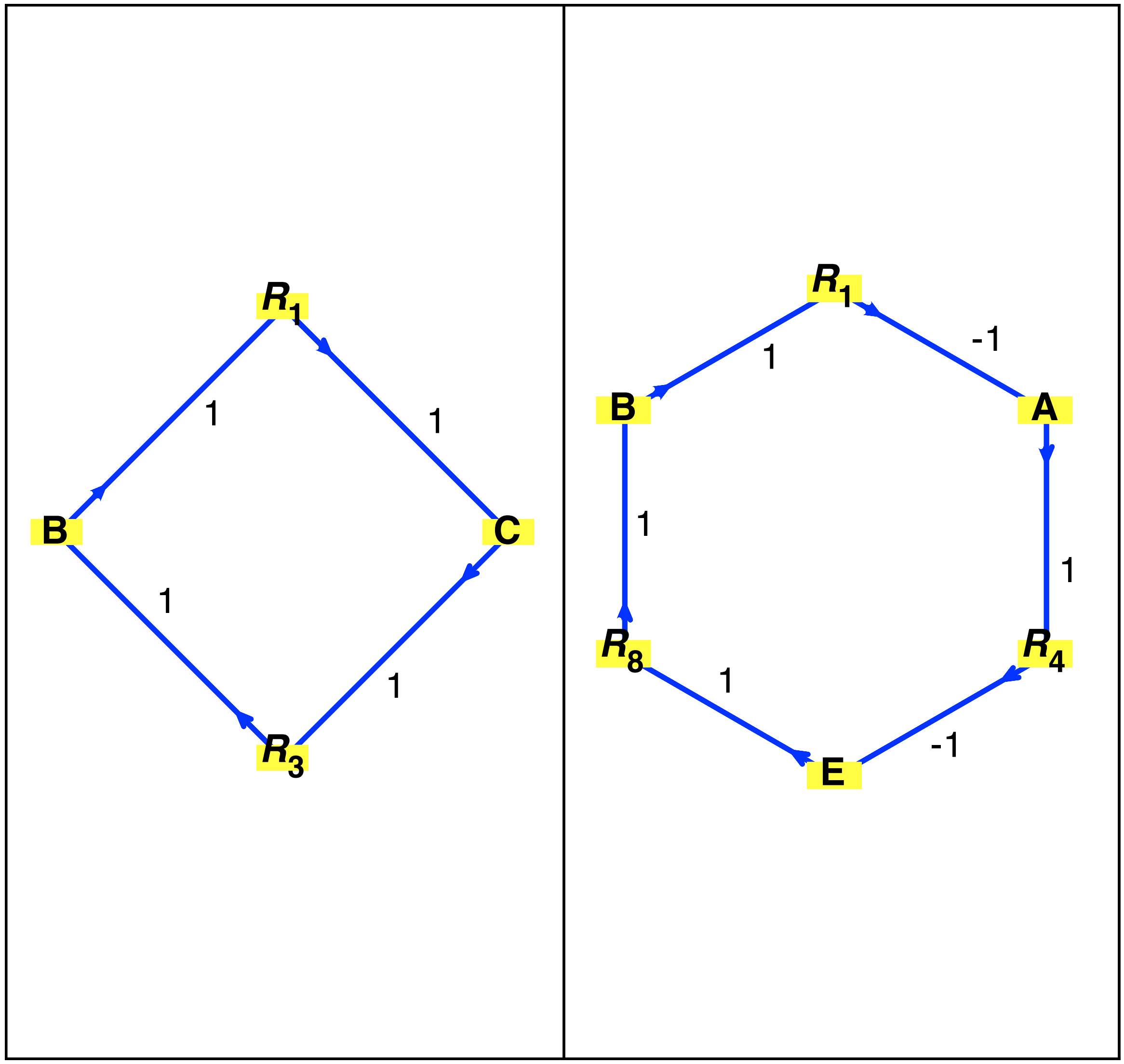
$selected := [[[[R_4, S_6], 1], [[S_6, R_6], 1], [[R_6, S_5], 1], [[S_5, R_4], 1]], [[[R_1, S_2], -1], [[S_2, R_7], 1], [[R_7, S_5], 1], [[S_5, R_4], 1], [[R_4, S_1], -1], [[S_1, R_1], 1]], [[[R_1,$ **(4.5.5)**

$S_3], 1], [[S_3, R_3], 1], [[R_3, S_2], 1], [[S_2, R_1], 1]], [[[R_1, S_1], -1], [[S_1, R_4], 1],$
$[[R_4, S_5], -1], [[S_5, R_8], 1], [[R_8, S_2], 1], [[S_2, R_1], 1]]]$

> *speciesord* := ["A", "B", "C", "D", "E", "F"] :

> *drawloops*(*selected*, *speciesord*)





Network 6

$A + B \rightleftharpoons C \rightarrow \mathrm{D} + B$
$\mathrm{D} + B \rightleftharpoons E \rightarrow F + B$
$\mathrm{D} \rightarrow A$
$F \rightarrow \mathrm{D}$

The stoichiometric matrix A is:

```
> A := Transpose(Matrix([[-1,-1, 1, 0, 0, 0],-[-1,-1, 1, 0, 0, 0], [0, 1,-1, 1, 0, 0], [0,
     -1, 0,-1, 1, 0],-[0,-1, 0,-1, 1, 0], [0, 1, 0, 0,-1, 1], [1, 0, 0,-1, 0, 0], [0, 0, 0, 1, 0,
     -1]]));
```

$$A := \begin{bmatrix} -1 & 1 & 0 & 0 & 0 & 0 & 1 & 0 \\ -1 & 1 & 1 & -1 & 1 & 1 & 0 & 0 \\ 1 & -1 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -1 & 1 & 0 & -1 & 1 \\ 0 & 0 & 0 & 1 & -1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & -1 \end{bmatrix} \quad \textbf{(4.6.1)}$$

>

Create the DSR-graph and find if there is a positive feedback loop through the competition.

> $mylabels := [\text{"A"}, \text{"B"}, \text{"C"}, \text{"D"}, \text{"E"}, \text{"F"}, seq(R[i], i = 1..8)]:$

> $findedgesDSR(mylabels, A)$

$\{[[\text{"A"}, R_1], 1], [[\text{"B"}, R_1], 1], [[\text{"B"}, R_4], 1], [[\text{"C"}, R_2], 1], [[\text{"C"}, R_3], 1], [[\text{"D"}, R_4], 1], [[\text{"D"}, R_7], 1], [[\text{"E"}, R_5], 1], [[\text{"E"}, R_6], 1], [[\text{"F"}, R_8], 1], [[R_1, \text{"A"}], -1], [[R_1, \text{"B"}], -1], [[R_1, \text{"C"}], 1], [[R_2, \text{"A"}], 1], [[R_2, \text{"B"}], 1], [[R_2, \text{"C"}], -1], [[R_3, \text{"B"}], 1], [[R_3, \text{"C"}], -1], [[R_3, \text{"D"}], 1], [[R_4, \text{"B"}], -1], [[R_4, \text{"D"}], -1], [[R_4, \text{"E"}], 1], [[R_5, \text{"B"}], 1], [[R_5, \text{"D"}], 1], [[R_5, \text{"E"}], -1], [[R_6, \text{"B"}], 1], [[R_6, \text{"E"}], -1], [[R_6, \text{"F"}], 1], [[R_7, \text{"A"}], 1], [[R_7, \text{"D"}], -1], [[R_8, \text{"D"}], 1], [[R_8, \text{"F"}], -1]\}$ **(4.6.2)**

>

check injectivity

> $isinjective(A)$

$$0 \quad \textbf{(4.6.3)}$$

> $isinjectiveextended(A)$

$$2 \quad \textbf{(4.6.4)}$$

>

Draw the loops

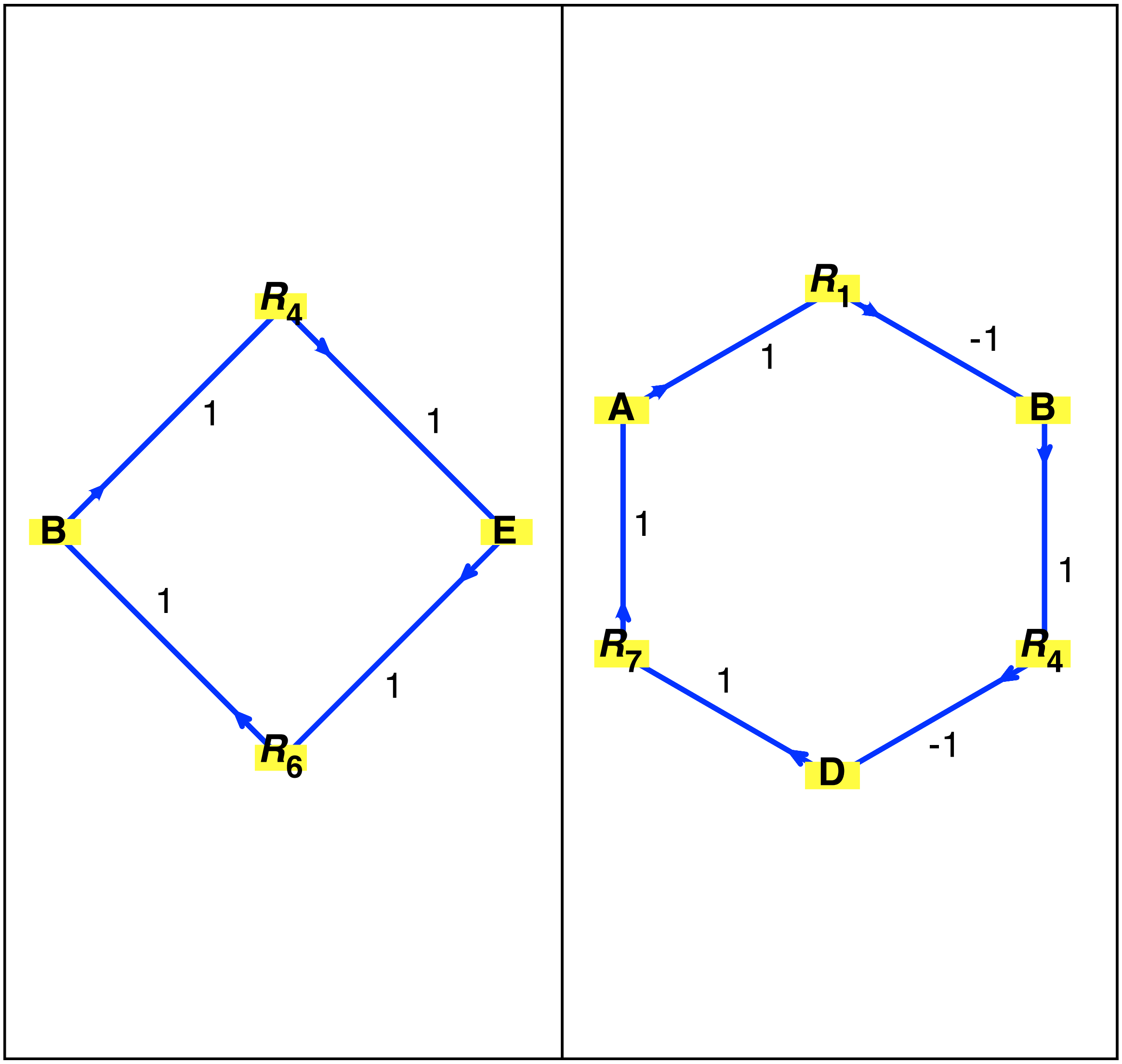
> $Z := findZ(A) : n := Dimension(A)[1] : m := Dimension(A)[2] : s := Rank(A) :$

> $selected := findloops(\ )$

$selected := [[[[R_4, S_5], 1], [[S_5, R_6], 1], [[R_6, S_2], 1], [[S_2, R_4], 1]], [[[R_1, S_2], -1], [[S_2, R_4], 1], [[R_4, S_4], -1], [[S_4, R_7], 1], [[R_7, S_1], 1], [[S_1, R_1], 1]]]$ **(4.6.5)**

> $speciesord := [\text{"A"}, \text{"B"}, \text{"C"}, \text{"D"}, \text{"E"}, \text{"F"}]:$

> $drawloops(selected, speciesord)$



>

Network 7 (5 × 5 network No. 1741)

$B \rightarrow A$
$A + \mathrm{D} \rightarrow C$
$A + C \rightleftharpoons E$
$C \rightarrow B + \mathrm{D}$

The stoichiometric matrix A is:

> $A := Transpose(Matrix([[1,-1,0,0,0],[-1,0,1,-1,0],[-1,0,-1,0,1],-[-1,0,-1,0,1],[0,1,-1,1,0]]));$

(4.7.1)

$$A := \begin{bmatrix} 1 & -1 & -1 & 1 & 0 \\ -1 & 0 & 0 & 0 & 1 \\ 0 & 1 & -1 & 1 & -1 \\ 0 & -1 & 0 & 0 & 1 \\ 0 & 0 & 1 & -1 & 0 \end{bmatrix} \quad \textbf{(4.7.1)}$$

\>

Create the DSR-graph and find if there is a positive feedback loop through the competition.

```
> mylabels := ["A", "B", "C", "D", "E", seq(R[i], i = 1 ..5)] :
> findedgesDSR(mylabels, A)
```

$\{[["A", R_2], 1], [["A", R_3], 1], [["B", R_1], 1], [["C", R_3], 1], [["C", R_5], 1], [["D", R_2], 1], [["E", R_4], 1], [[R_1, "A"], 1], [[R_1, "B"], -1], [[R_2, "A"], -1], [[R_2, "C"], 1], [[R_2, "D"], -1], [[R_3, "A"], -1], [[R_3, "C"], -1], [[R_3, "E"], 1], [[R_4, "A"], 1], [[R_4, "C"], 1], [[R_4, "E"], -1], [[R_5, "B"], 1], [[R_5, "C"], -1], [[R_5, "D"], 1]\}$ **(4.7.2)**

\>

check injectivity

```
> isinjective(A)
```

$$0 \quad \textbf{(4.7.3)}$$

```
> isinjectiveextended(A)
```

$$2 \quad \textbf{(4.7.4)}$$

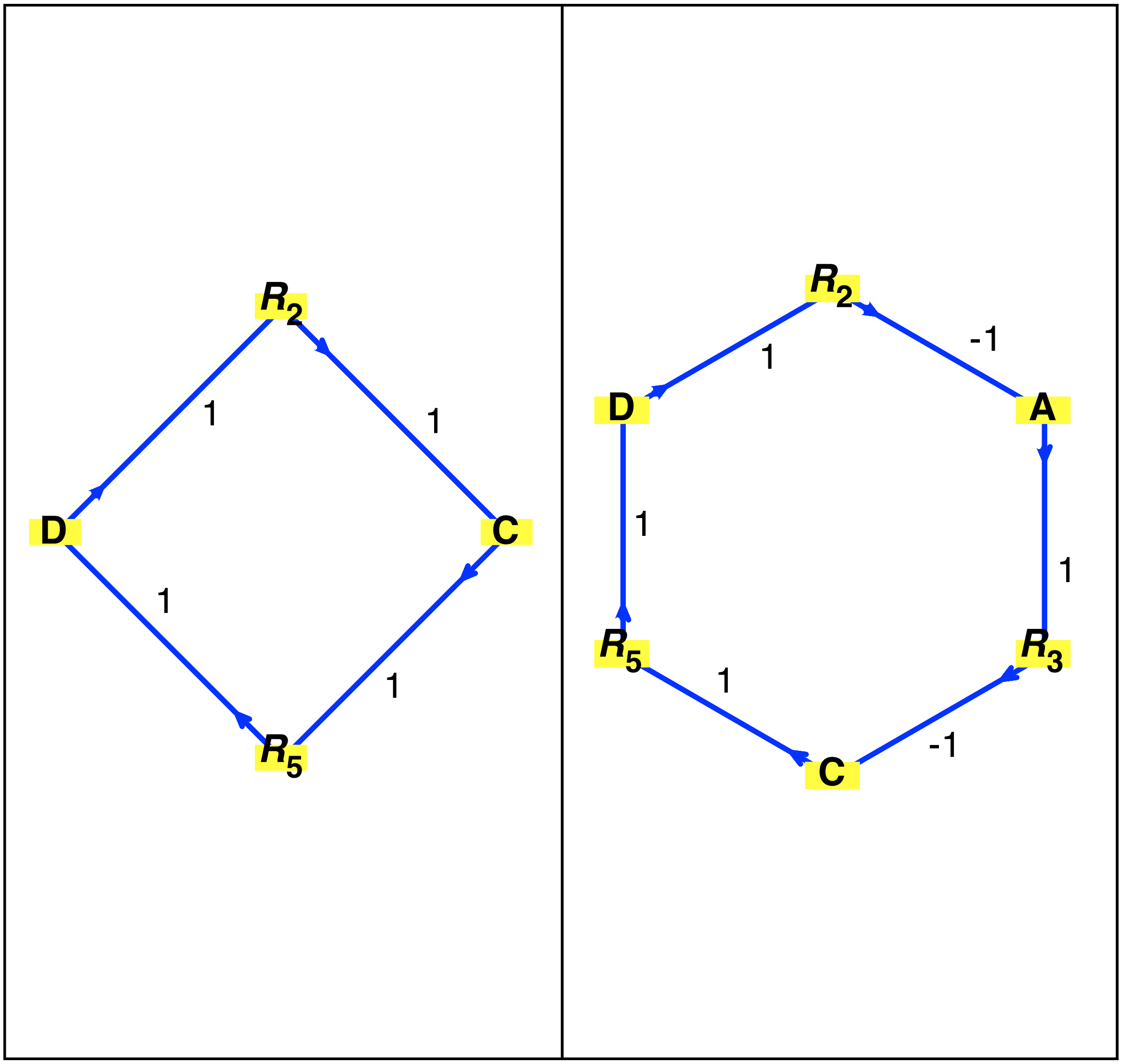
\>

Draw the loops

```
> Z := findZ(A) : n := Dimension(A)[1] : m := Dimension(A)[2] : s := Rank(A) :
> selected := findloops( )
```

$selected := [[[[R_2, S_3], 1], [[S_3, R_5], 1], [[R_5, S_4], 1], [[S_4, R_2], 1]], [[[R_2, S_1], -1], [[S_1, R_3], 1], [[R_3, S_3], -1], [[S_3, R_5], 1], [[R_5, S_4], 1], [[S_4, R_2], 1]]]$ **(4.7.5)**

```
> speciesord := ["A", "B", "C", "D", "E", "F"] :
> drawloops(selected, speciesord)
```



>

Network 8 (5 × 5 network No. 1742)

$B \rightarrow A$
$A + \mathrm{D} \rightarrow C$
$A + C \rightarrow E$
$C \rightarrow B + \mathrm{D}$
$E \rightarrow B + C$

The stoichiometric matrix A is:

> $A := Transpose(Matrix([[1, -1, 0, 0, 0], [-1, 0, 1, -1, 0], [-1, 0, -1, 0, 1], [0, 1, -1, 1, 0], [0, 1, 1, 0, -1]]));$

$$A := \begin{bmatrix} 1 & -1 & -1 & 0 & 0 \\ -1 & 0 & 0 & 1 & 1 \\ 0 & 1 & -1 & -1 & 1 \\ 0 & -1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & -1 \end{bmatrix} \quad \textbf{(4.8.1)}$$

>

Create the DSR-graph and find if there is a positive feedback loop through the competition.

> $mylabels := [\text{"A"}, \text{"B"}, \text{"C"}, \text{"D"}, \text{"E"}, seq(R[i], i = 1..5)]:$

> $findedgesDSR(mylabels, A)$

$$\{[[\text{"A"}, R_2], 1], [[\text{"A"}, R_3], 1], [[\text{"B"}, R_1], 1], [[\text{"C"}, R_3], 1], [[\text{"C"}, R_4], 1], [[\text{"D"}, R_2], 1], [[\text{"E"}, R_5], 1], [[R_1, \text{"A"}], 1], [[R_1, \text{"B"}], -1], [[R_2, \text{"A"}], -1], [[R_2, \text{"C"}], 1], [[R_2, \text{"D"}], -1], [[R_3, \text{"A"}], -1], [[R_3, \text{"C"}], -1], [[R_3, \text{"E"}], 1], [[R_4, \text{"B"}], 1], [[R_4, \text{"C"}], -1], [[R_4, \text{"D"}], 1], [[R_5, \text{"B"}], 1], [[R_5, \text{"C"}], 1], [[R_5, \text{"E"}], -1]\} \quad \textbf{(4.8.2)}$$

>

check injectivity

> $isinjective(A)$

$$0 \quad \textbf{(4.8.3)}$$

> $isinjectiveextended(A)$

$$0 \quad \textbf{(4.8.4)}$$

>

Draw the loops

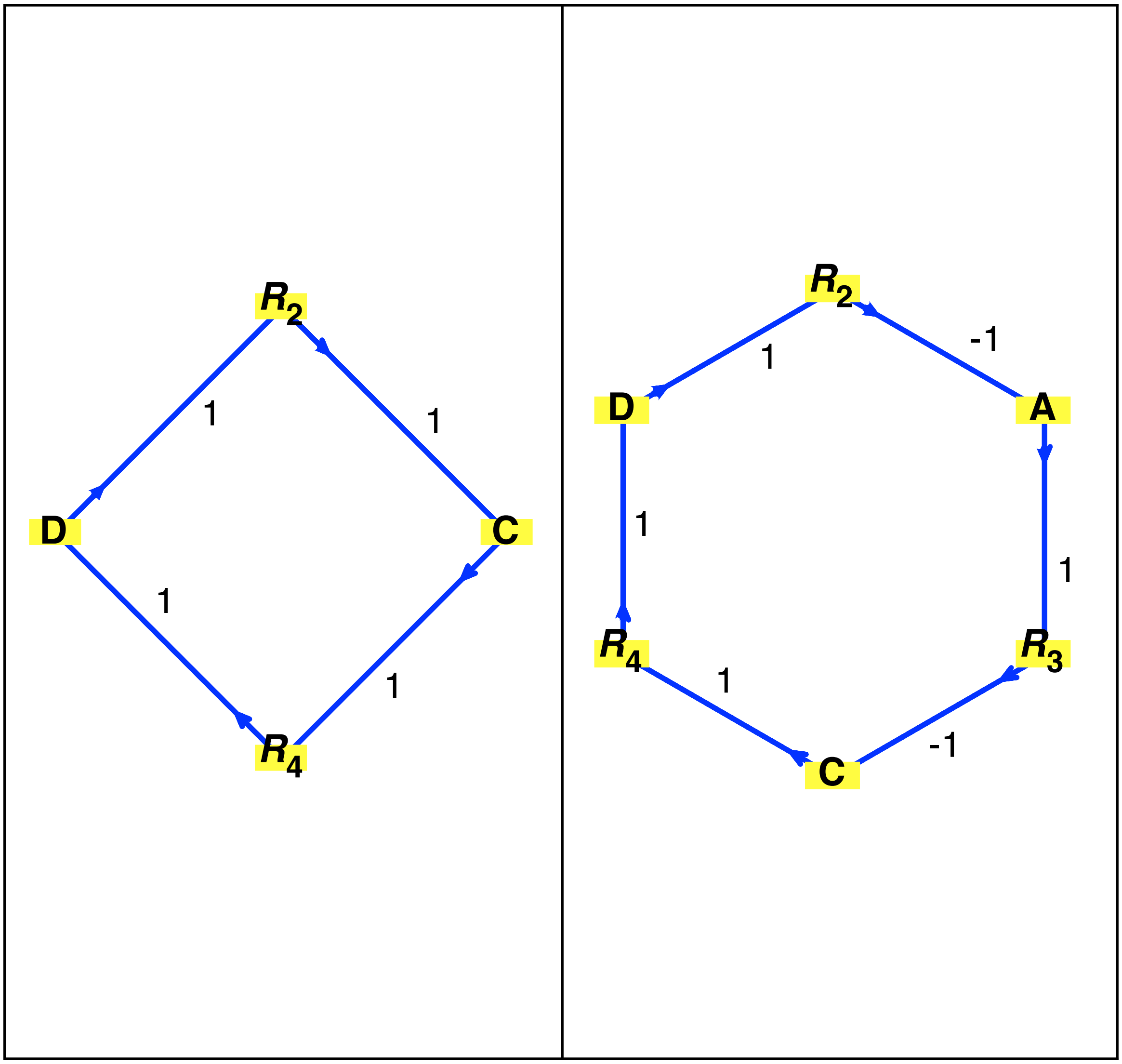
> $Z := findZ(A) : n := Dimension(A)[1] : m := Dimension(A)[2] : s := Rank(A) :$

> $selected := findloops(\,)$

$$selected := [[[[R_2, S_3], 1], [[S_3, R_4], 1], [[R_4, S_4], 1], [[S_4, R_2], 1]], [[[R_2, S_1], -1], [[S_1, R_3], 1], [[R_3, S_3], -1], [[S_3, R_4], 1], [[R_4, S_4], 1], [[S_4, R_2], 1]]] \quad \textbf{(4.8.5)}$$

> $speciesord := [\text{"A"}, \text{"B"}, \text{"C"}, \text{"D"}, \text{"E"}, \text{"F"}]:$

> $drawloops(selected, speciesord)$



>

Monostable networks

<u>**IMPORTNTANT: Network 2956, 2957, 2958 are similar to bistable networks 1741 & 1742. Need to further analyze their difference.**</u>

If we impose the condition strictly as "not in any of intersecting edges", we only have network 2958 meeting both

conditions (however, they are not realistic), network 2956 meeting condition 2 (not realistic), and network 1796, 1518, 2970, (however they are also not realistic)!!

5×5 networks with competing PF loop intersecting with other PF loops

```
> speciesord := ["A", "B", "C", "D", "E"] :
> uniquefolder := "5species/nonmultistationary/unique_competitionloop_intersectingloops" :
>
```

Network 2962 (meet neither, not realistic)

$B + C \rightarrow A$

$C + D \rightarrow B$

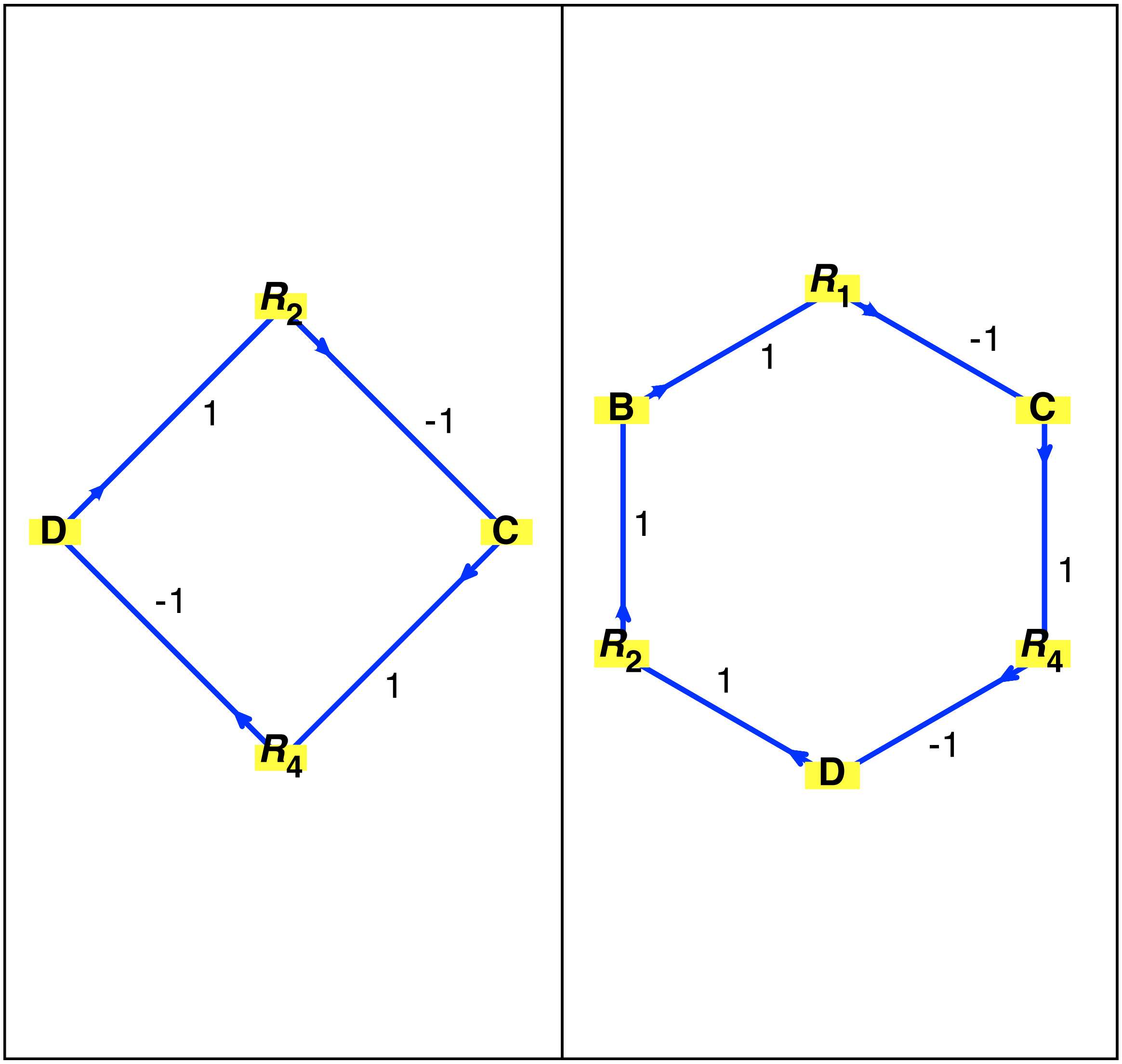
$A \rightarrow B + C$

$C + D \rightarrow E$

$E \rightarrow C + D$

```
> A := ImportMatrix(cat(uniquefolder, "/injective1_2962.csv")); Z := findZ(A) : selected
      := findloops(A, Z) : drawloops(selected, speciesord)
```

$$A := \begin{bmatrix} 1 & 0 & -1 & 0 & 0 \\ -1 & 1 & 1 & 0 & 0 \\ -1 & -1 & 1 & -1 & 1 \\ 0 & -1 & 0 & -1 & 1 \\ 0 & 0 & 0 & 1 & -1 \end{bmatrix}$$



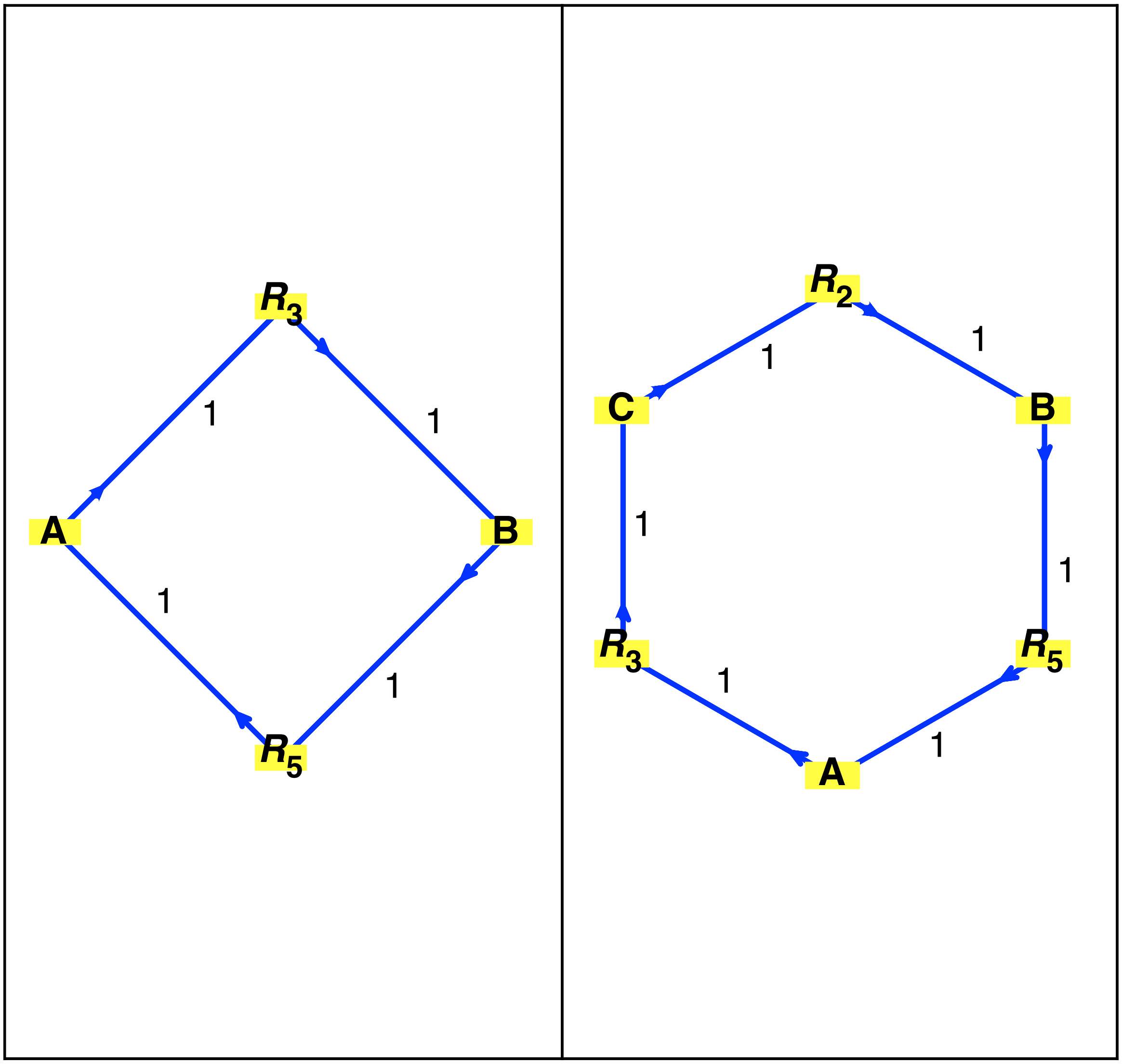
>

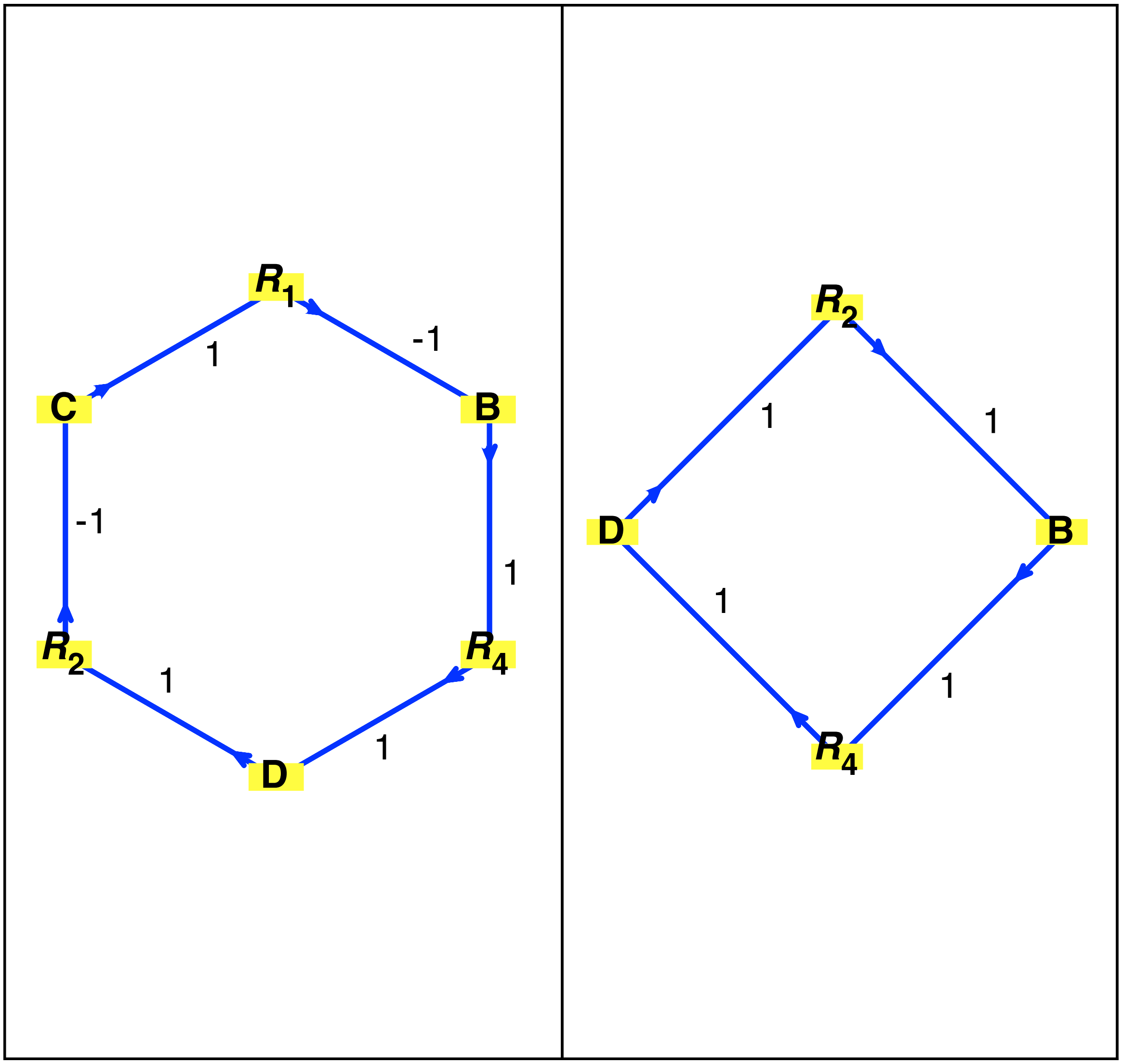
Network 2956 (meet condition 2, not realistic), three competing reactions

$B + C \rightarrow A$
$\mathrm{D} + C \rightarrow B$
$A \rightarrow B + C$
$B \rightarrow \mathrm{D} + E$
$E + B \rightarrow A$

> $A := ImportMatrix(cat(uniquefolder, \text{"/injectiveEx1\_2956.csv"})); Z := findZ(A)$:
$selected := findloops(A, Z) : drawloops(selected, speciesord)$

$$A := \begin{bmatrix} 1 & 0 & -1 & 0 & 1 \\ -1 & 1 & 1 & -1 & -1 \\ -1 & -1 & 1 & 0 & 0 \\ 0 & -1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & -1 \end{bmatrix}$$





>

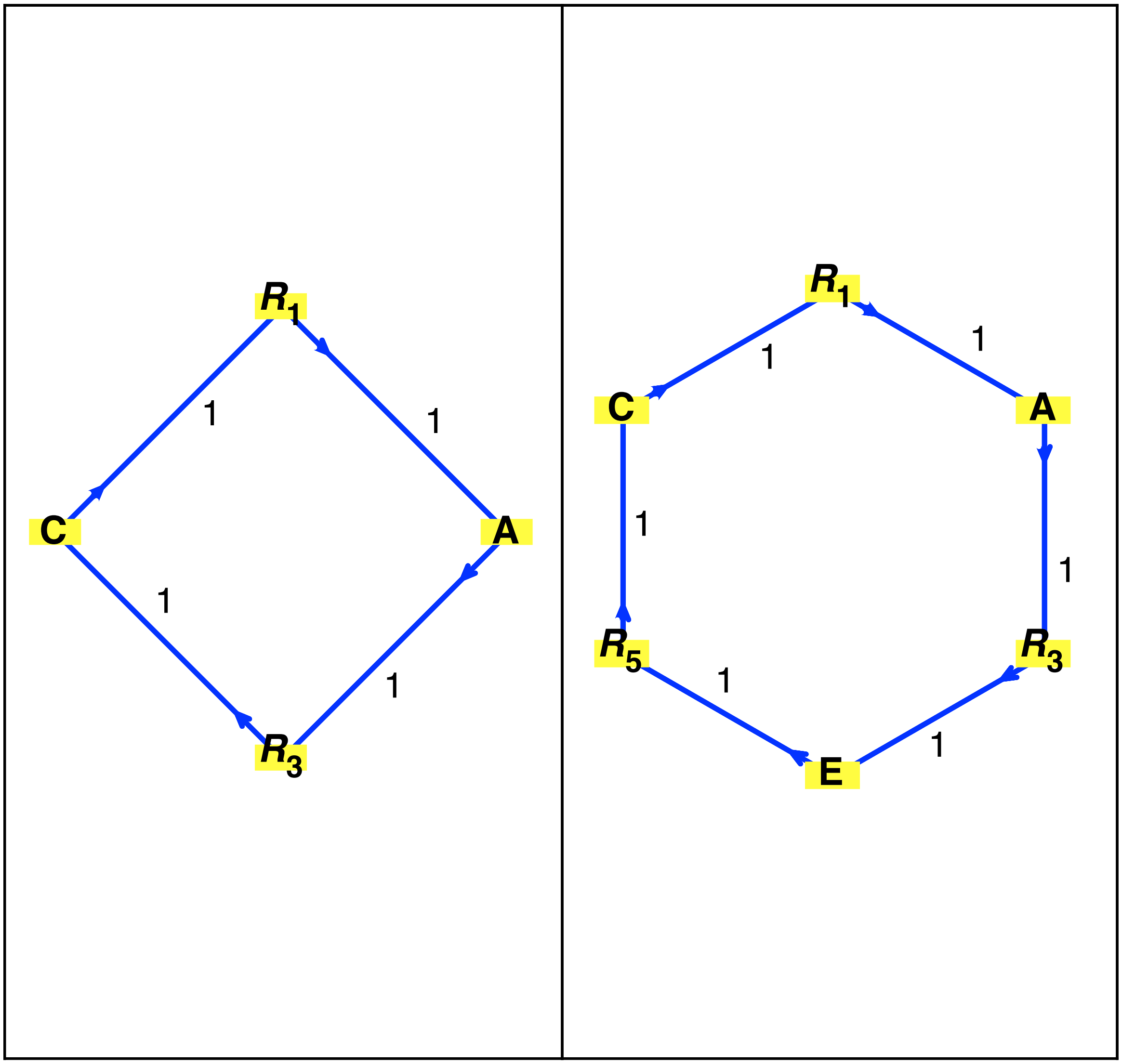
Meet condition 1 & 2. NB: E is same as C

Network 2988 (meet neither, not realistic)

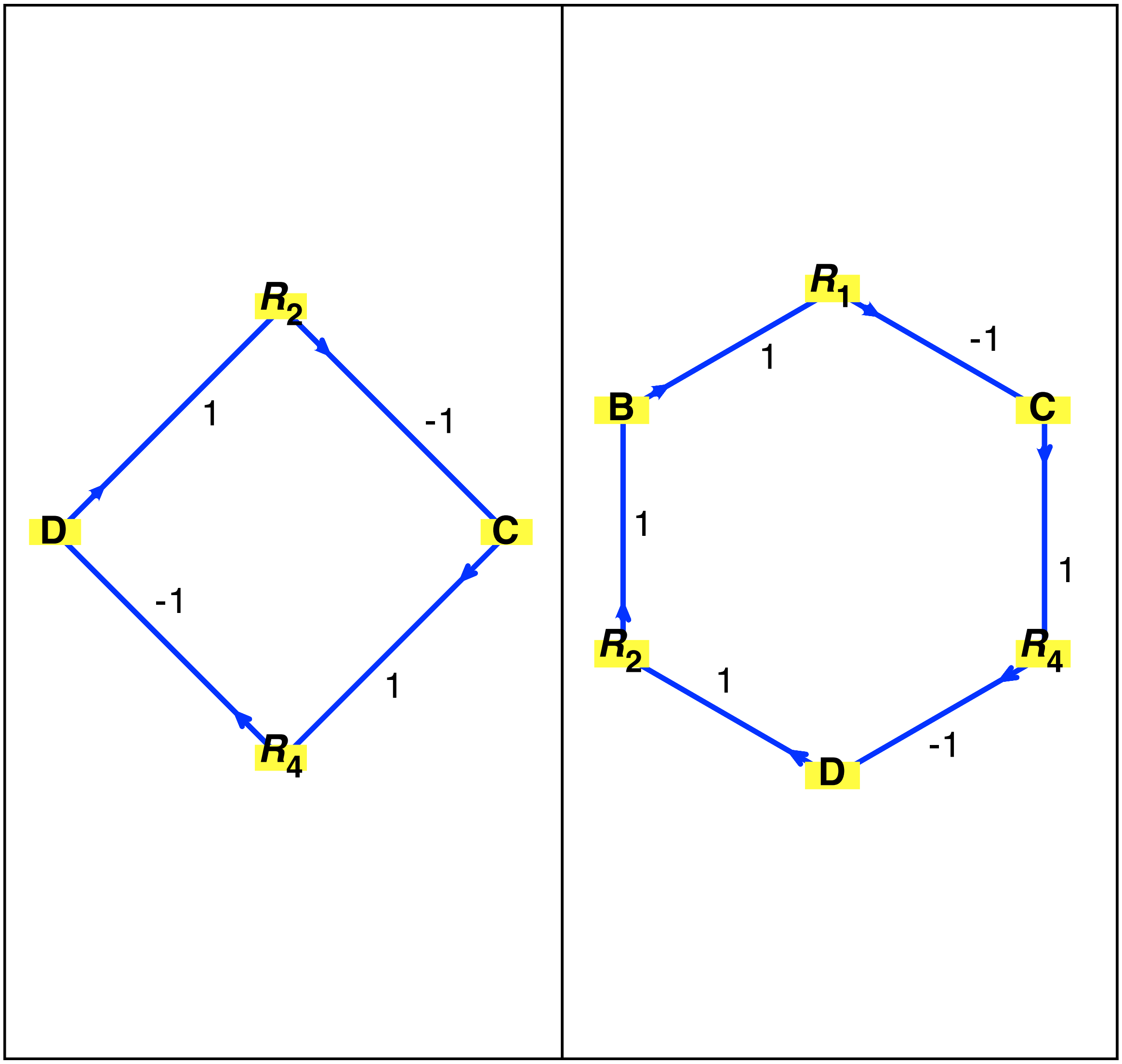
$B + C \rightarrow A$
$C + \mathrm{D} \rightarrow B$
$A \rightarrow C + E$
$C + \mathrm{D} \rightleftharpoons E$

> $A := ImportMatrix(cat(uniquefolder, \text{"/injectiveEx1\_2988.csv"})); Z := findZ(A):$
> $selected := findloops(A, Z) : drawloops(selected, speciesord)$

$$A := \begin{bmatrix} 1 & 0 & -1 & 0 & 0 \\ -1 & 1 & 0 & 0 & 0 \\ -1 & -1 & 1 & -1 & 1 \\ 0 & -1 & 0 & -1 & 1 \\ 0 & 0 & 1 & 1 & -1 \end{bmatrix}$$



R_1
C
A
R_3
1
1
1
1
R_1
C
A
R_5
R_3
E
1
1
1
1
1
1



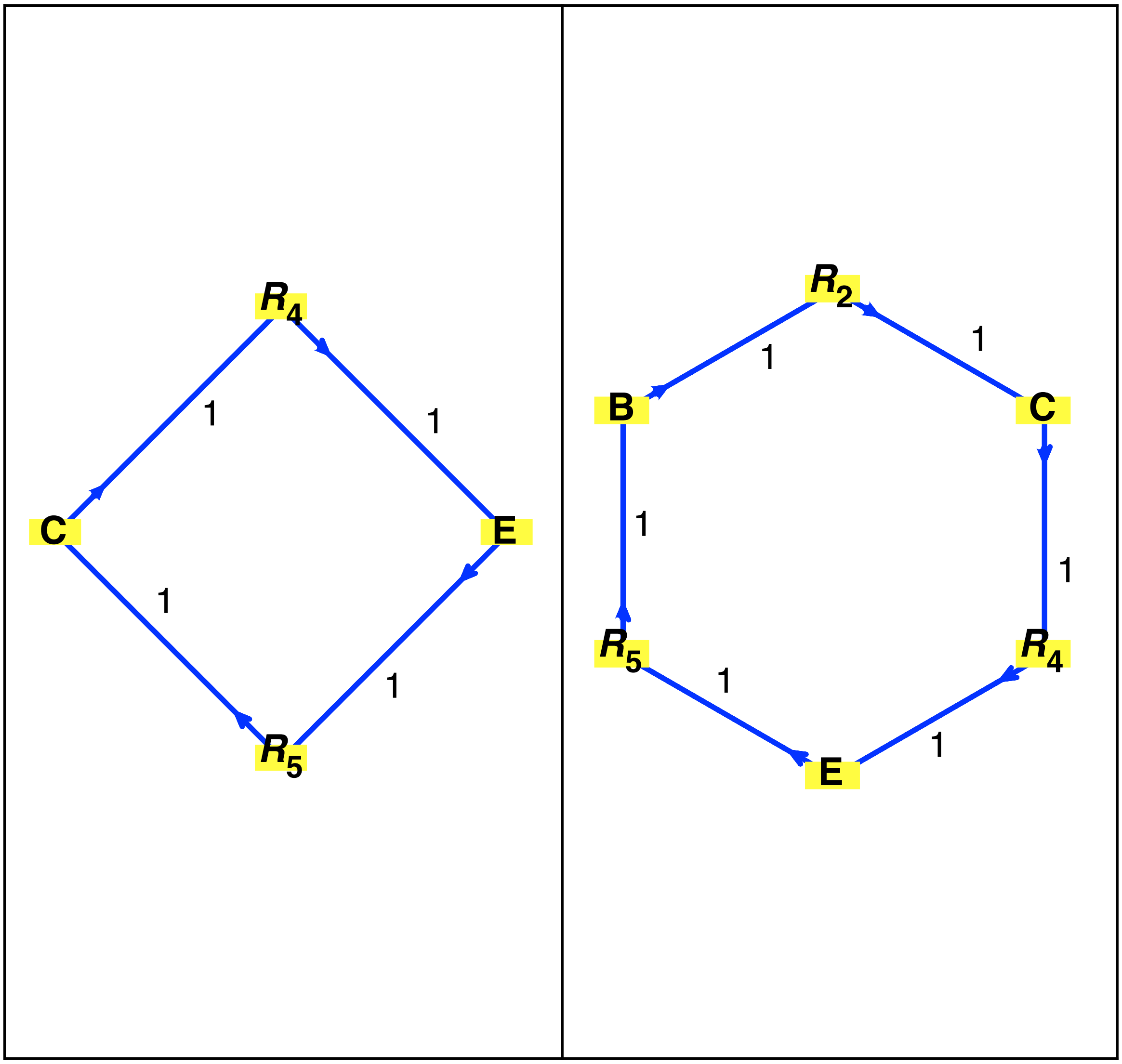
>

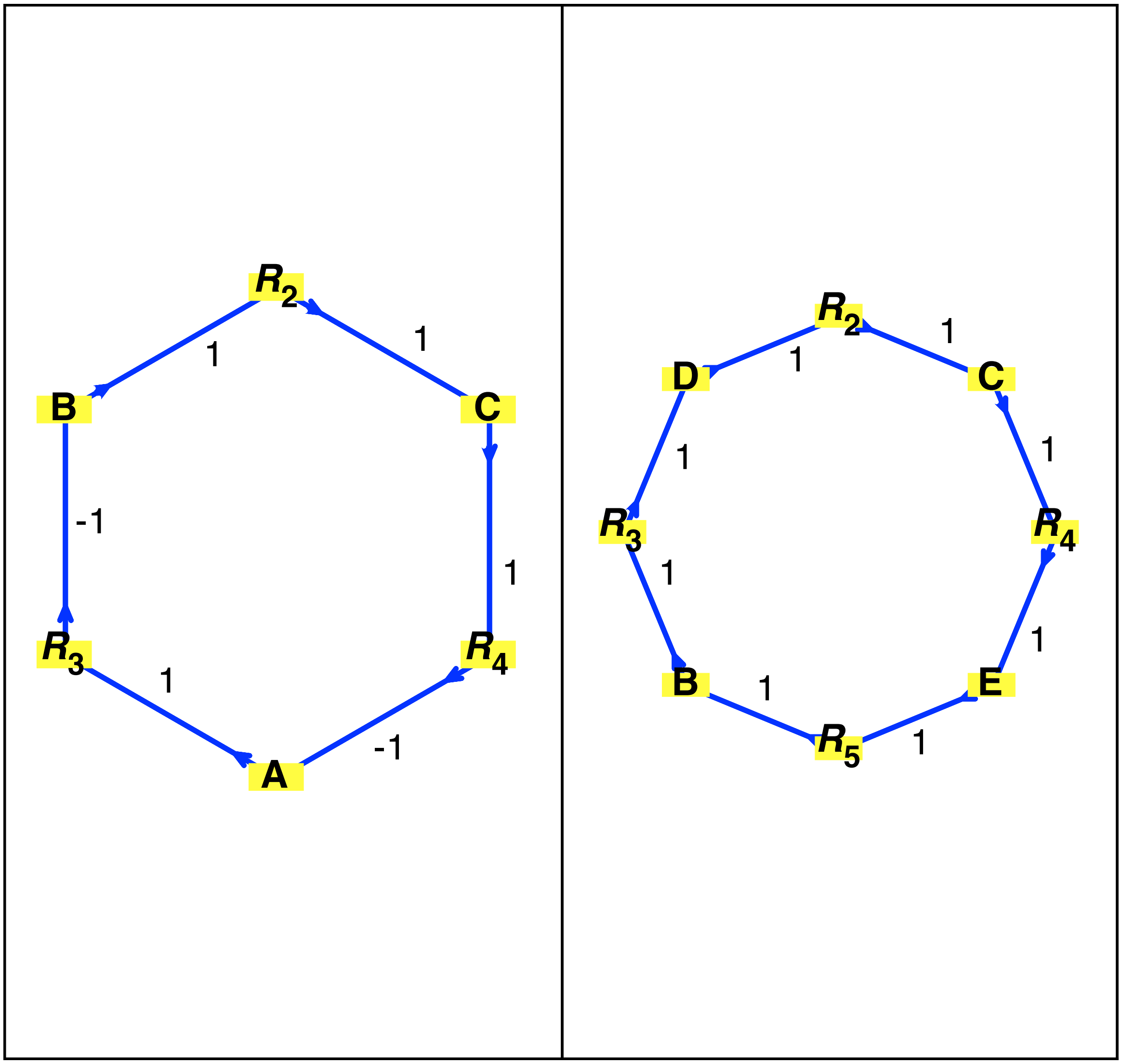
Network 1473 (meet neither, maybe not realistic), three competing reactions

$B \rightarrow A$
$B + \mathrm{D} \rightarrow C$
$A + B \rightarrow \mathrm{D}$
$A + C \rightarrow E$
$E \rightarrow B + C$

> $A := ImportMatrix(cat(uniquefolder, \text{"/injectiveEx3\_1473.csv"}));\ Z := findZ(A):$
> $selected := findloops(A, Z) : drawloops(selected, speciesord)$

$$A := \begin{bmatrix} 1 & 0 & -1 & -1 & 0 \\ -1 & -1 & -1 & 0 & 1 \\ 0 & 1 & 0 & -1 & 1 \\ 0 & -1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & -1 \end{bmatrix}$$





>

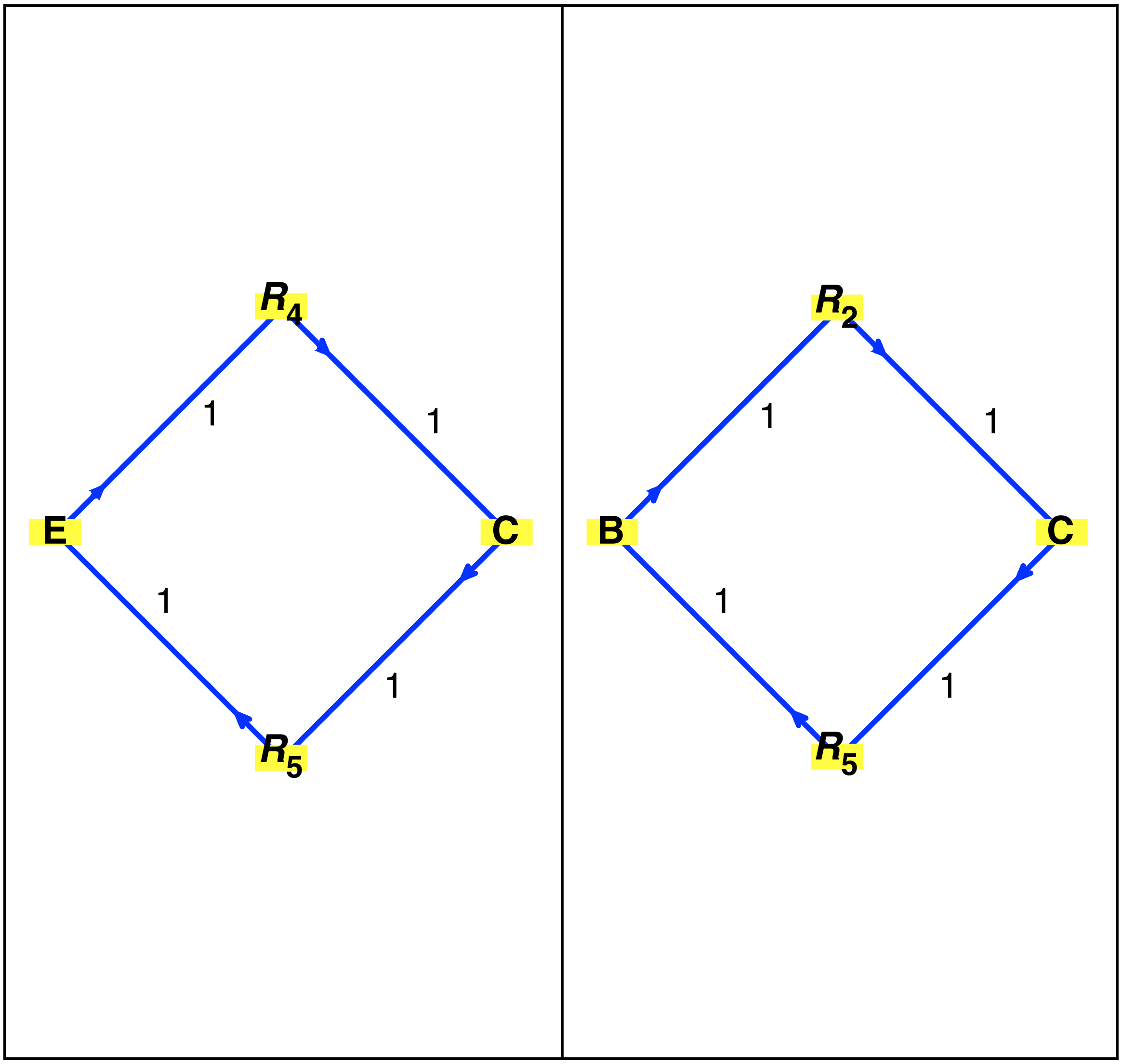
Meet both conditions (?). NB: E is tetramer, C is trimer, D is dimer

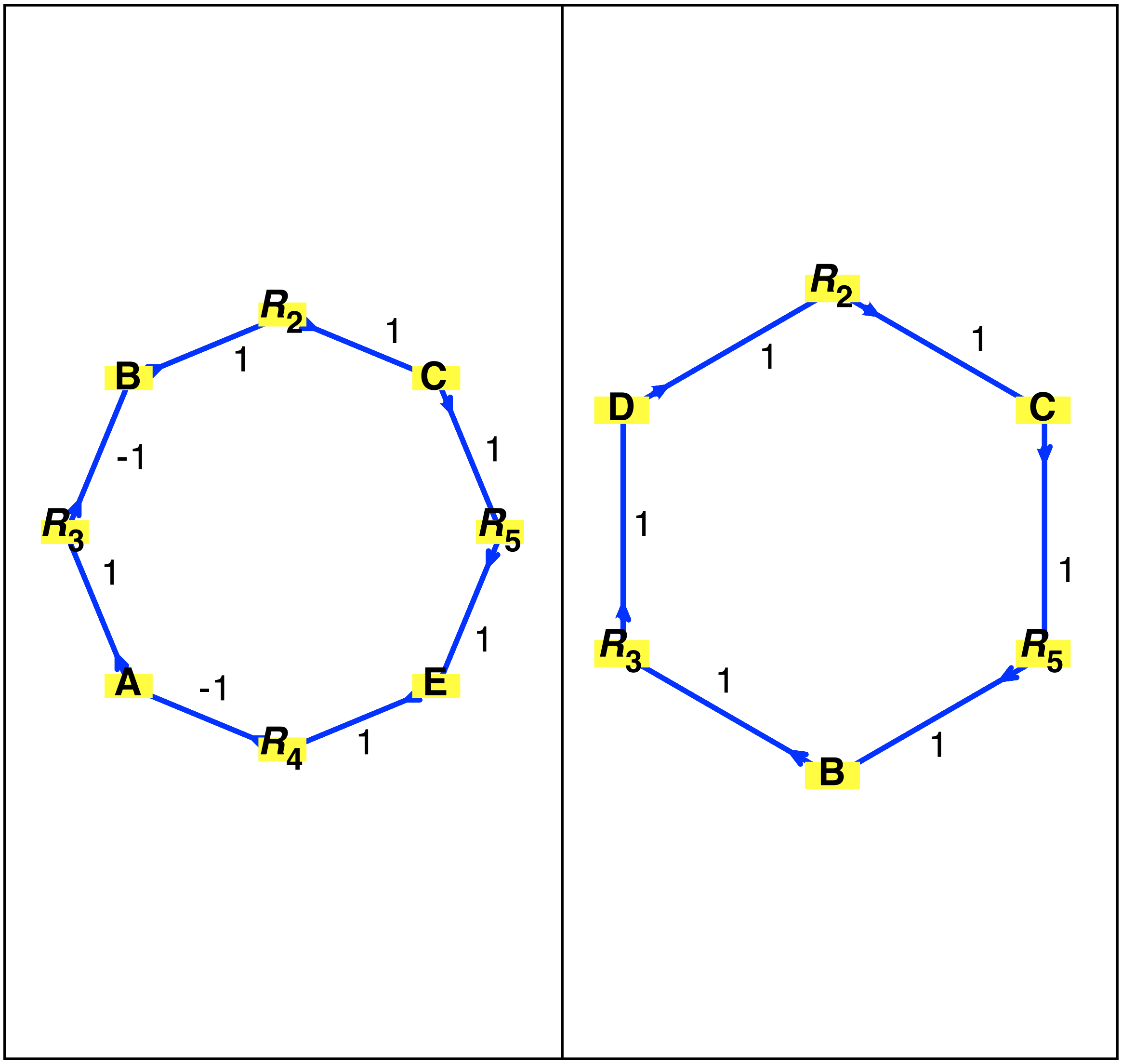
Network 1474 (meet neither, maybe not realistic), three competing reactions

$B \rightarrow A$
$B + \mathrm{D} \rightarrow C$
$A + B \rightarrow \mathrm{D}$
$A + E \rightarrow C$
$C \rightarrow B + E$

> $A := ImportMatrix(cat(uniquefolder, \text{"/injectiveEx3\_1474.csv"})); Z := findZ(A) :$
> $selected := findloops(A, Z) : drawloops(selected, speciesord)$

$$A := \begin{bmatrix} 1 & 0 & -1 & -1 & 0 \\ -1 & -1 & -1 & 0 & 1 \\ 0 & 1 & 0 & 1 & -1 \\ 0 & -1 & 1 & 0 & 0 \\ 0 & 0 & 0 & -1 & 1 \end{bmatrix}$$





>

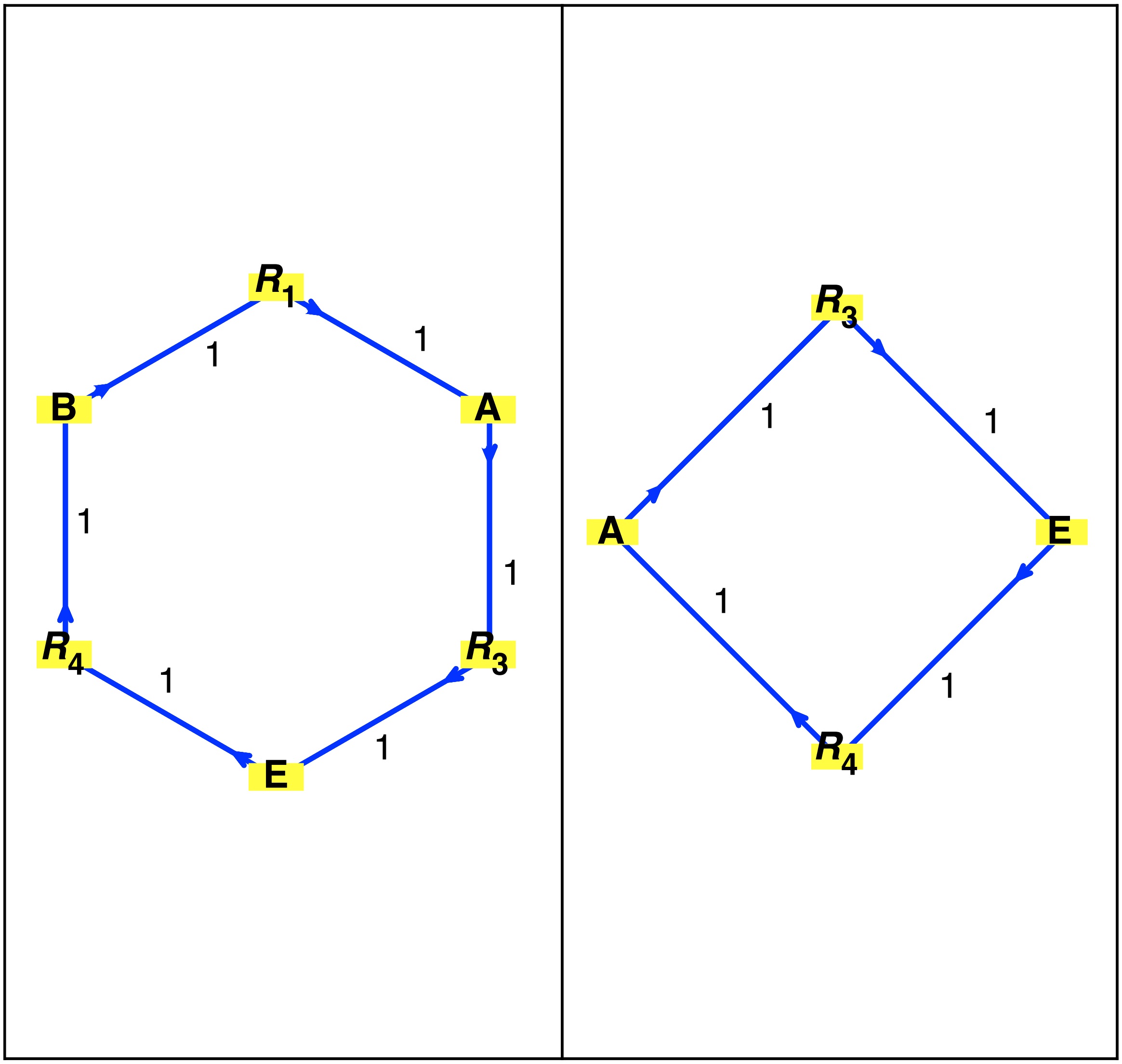
Meet both (?). NB: C is trimer, D is dimer, E is dimer

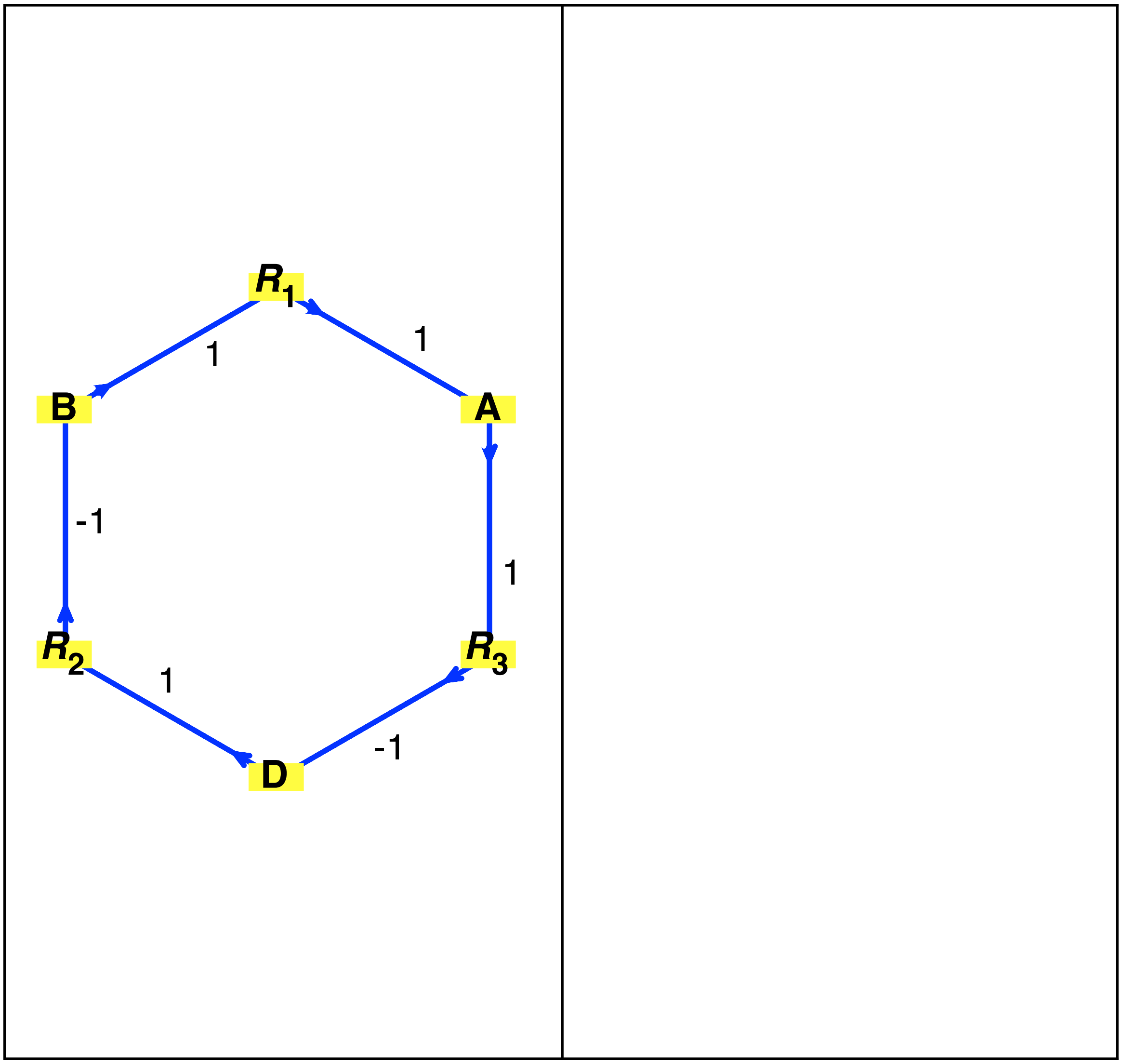
Network 1518 (meat condition 1, not realistic)

$B \rightarrow A$
$B + \mathrm{D} \rightarrow C$
$A + \mathrm{D} \rightarrow E$
$E \rightarrow A + B$
$C \rightarrow B + \mathrm{D}$

```
> A := ImportMatrix(cat(uniquefolder, "/injectiveEx3_1518.csv")); Z := findZ(A) :
    selected := findloops(A, Z) : drawloops(selected, speciesord)
```

$$A := \begin{bmatrix} 1 & 0 & -1 & 1 & 0 \\ -1 & -1 & 0 & 1 & 1 \\ 0 & 1 & 0 & 0 & -1 \\ 0 & -1 & -1 & 0 & 1 \\ 0 & 0 & 1 & -1 & 0 \end{bmatrix}$$





>

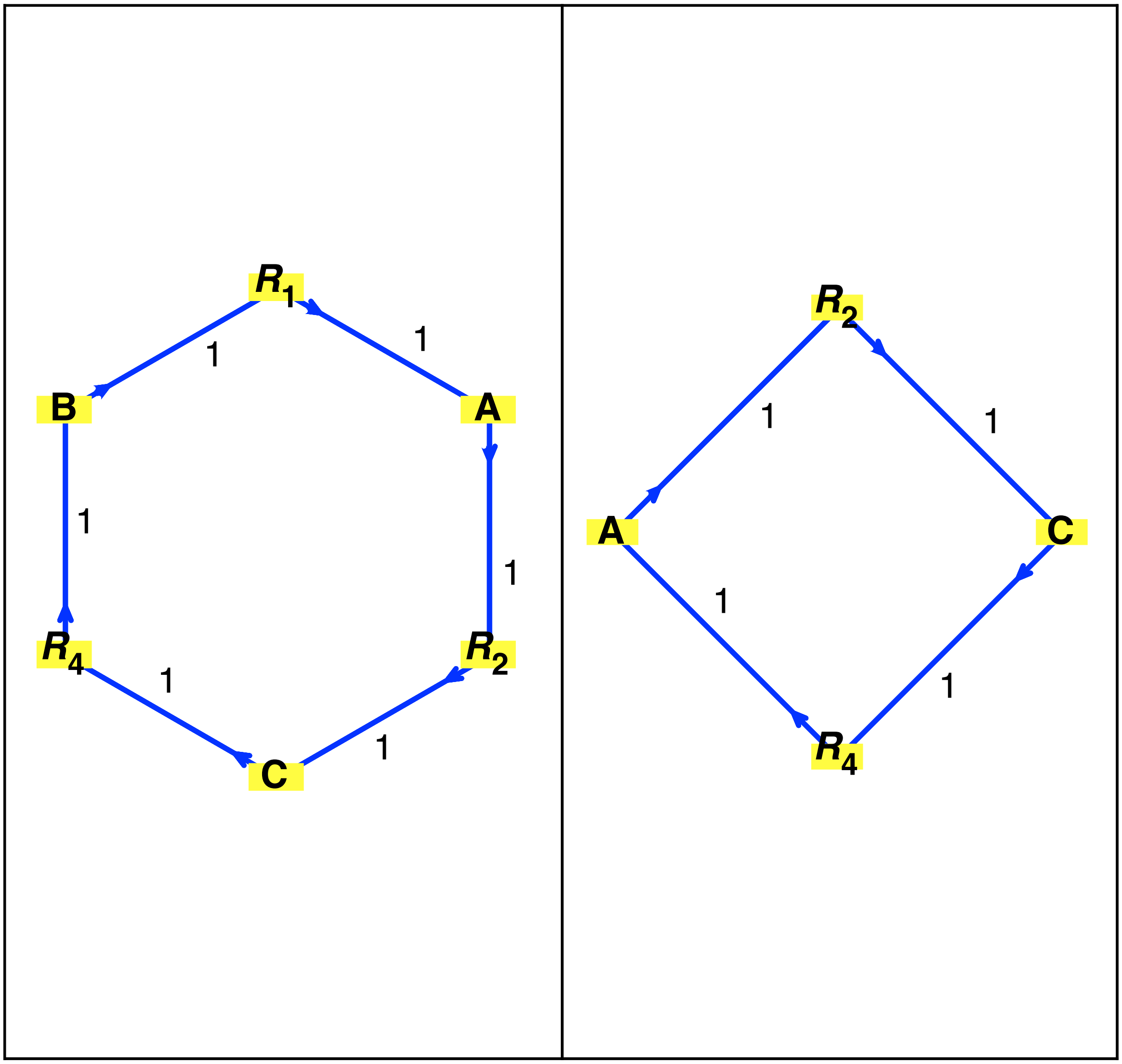
Meet both (?). NB: everything seems going to A

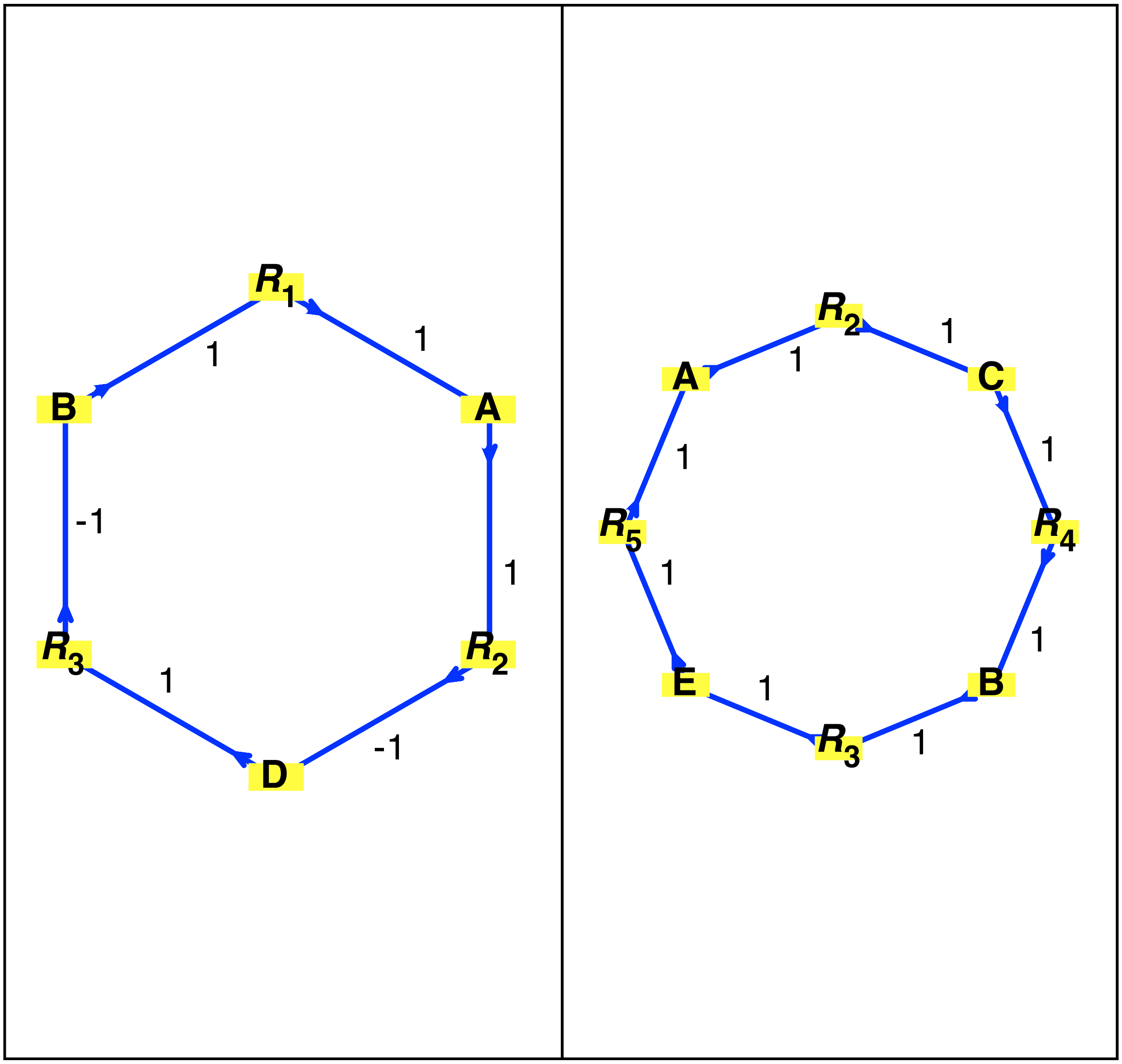
Network 1796 (meat condition 1, not realistic)

$B \rightarrow A$
$A + \mathrm{D} \rightarrow C$
$B + \mathrm{D} \rightarrow E$
$C \rightarrow A + B$
$E \rightarrow A + \mathrm{D}$

> $A := ImportMatrix(cat(uniquefolder, \text{"/injectiveEx3\_1796.csv"})); Z := findZ(A):$
> $selected := findloops(A, Z) : drawloops(selected, speciesord)$

$$A := \begin{bmatrix} 1 & -1 & 0 & 1 & 1 \\ -1 & 0 & -1 & 1 & 0 \\ 0 & 1 & 0 & -1 & 0 \\ 0 & -1 & -1 & 0 & 1 \\ 0 & 0 & 1 & 0 & -1 \end{bmatrix}$$





>

Meet condition 1. NB: A, B, D are three states, and all go to A.

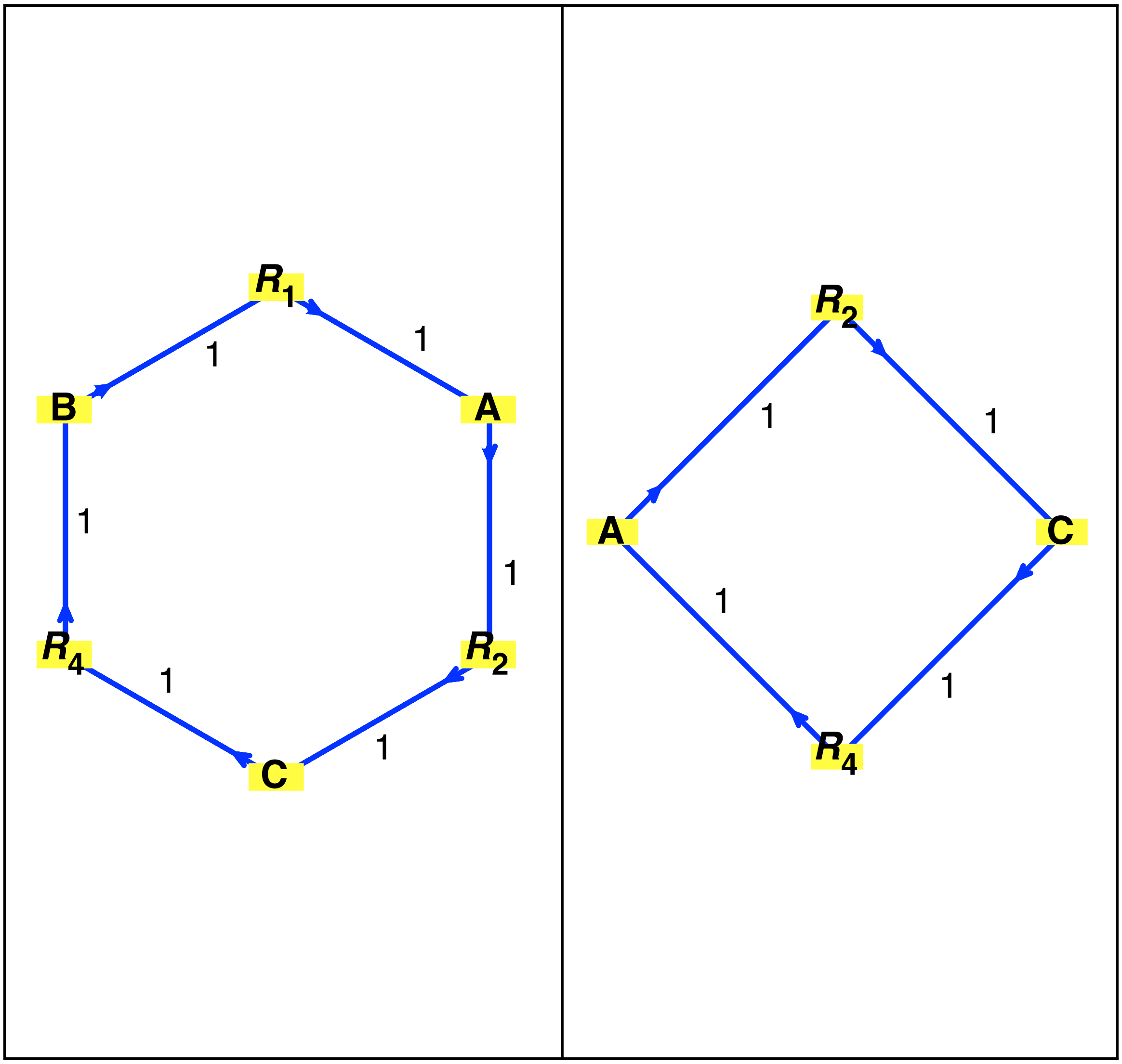
NB!!! all 1473, 1474, 1518, 1796 contains the same pattern: the three intersecting loops in 1518

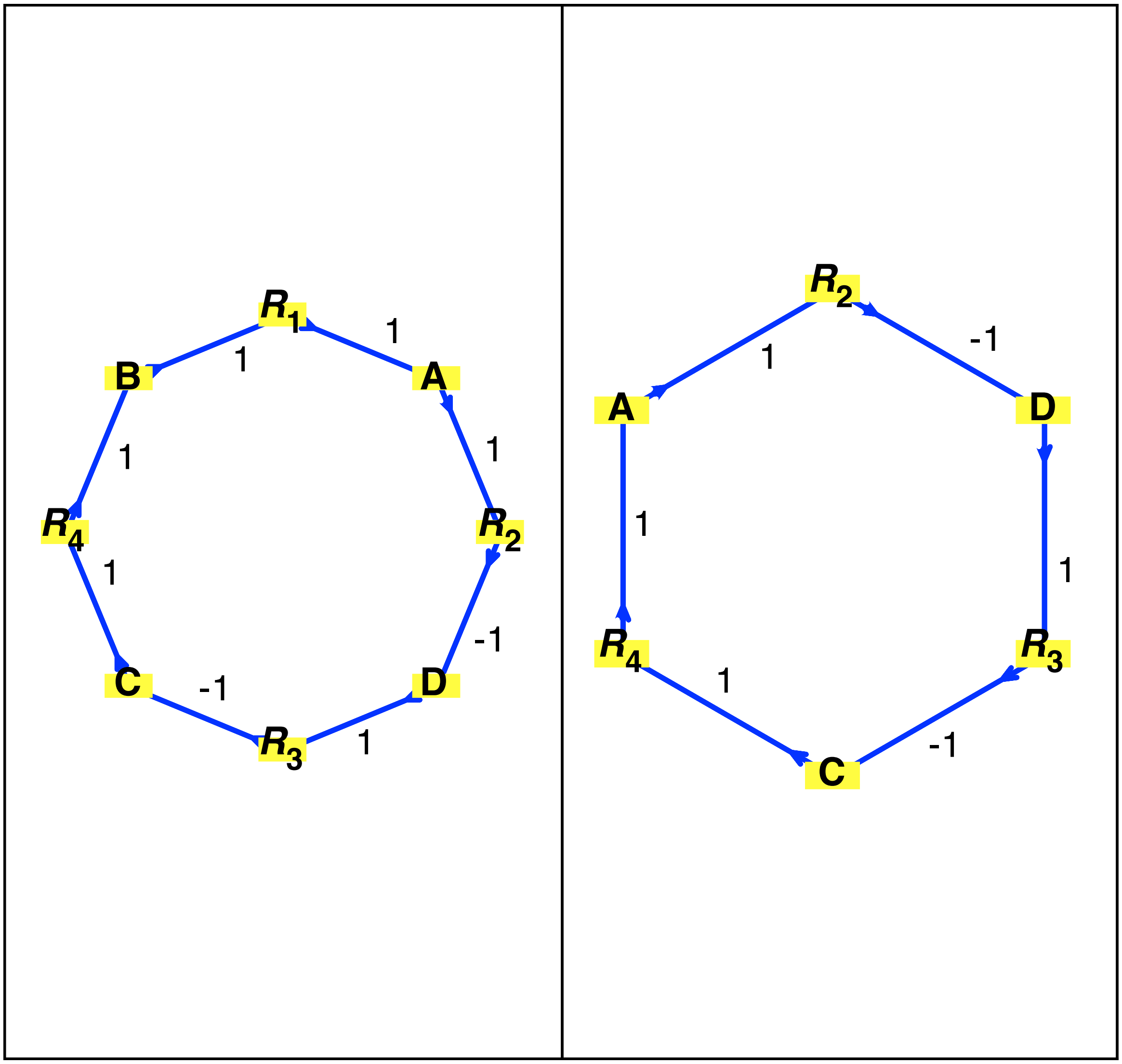
Network 1814 (meet neither, not realistic)

$B \rightarrow A$
$A + \mathrm{D} \rightarrow C$
$C + \mathrm{D} \rightarrow E$
$C \rightarrow A + B$
$E \rightarrow C + \mathrm{D}$

> $A := ImportMatrix(cat(uniquefolder, \text{"/injectiveEx3\_1814.csv"})); Z := findZ(A)$: $selected := findloops(A, Z)$: $drawloops(selected, speciesord)$

$$A := \begin{bmatrix} 1 & -1 & 0 & 1 & 0 \\ -1 & 0 & 0 & 1 & 0 \\ 0 & 1 & -1 & -1 & 1 \\ 0 & -1 & -1 & 0 & 1 \\ 0 & 0 & 1 & 0 & -1 \end{bmatrix}$$





>

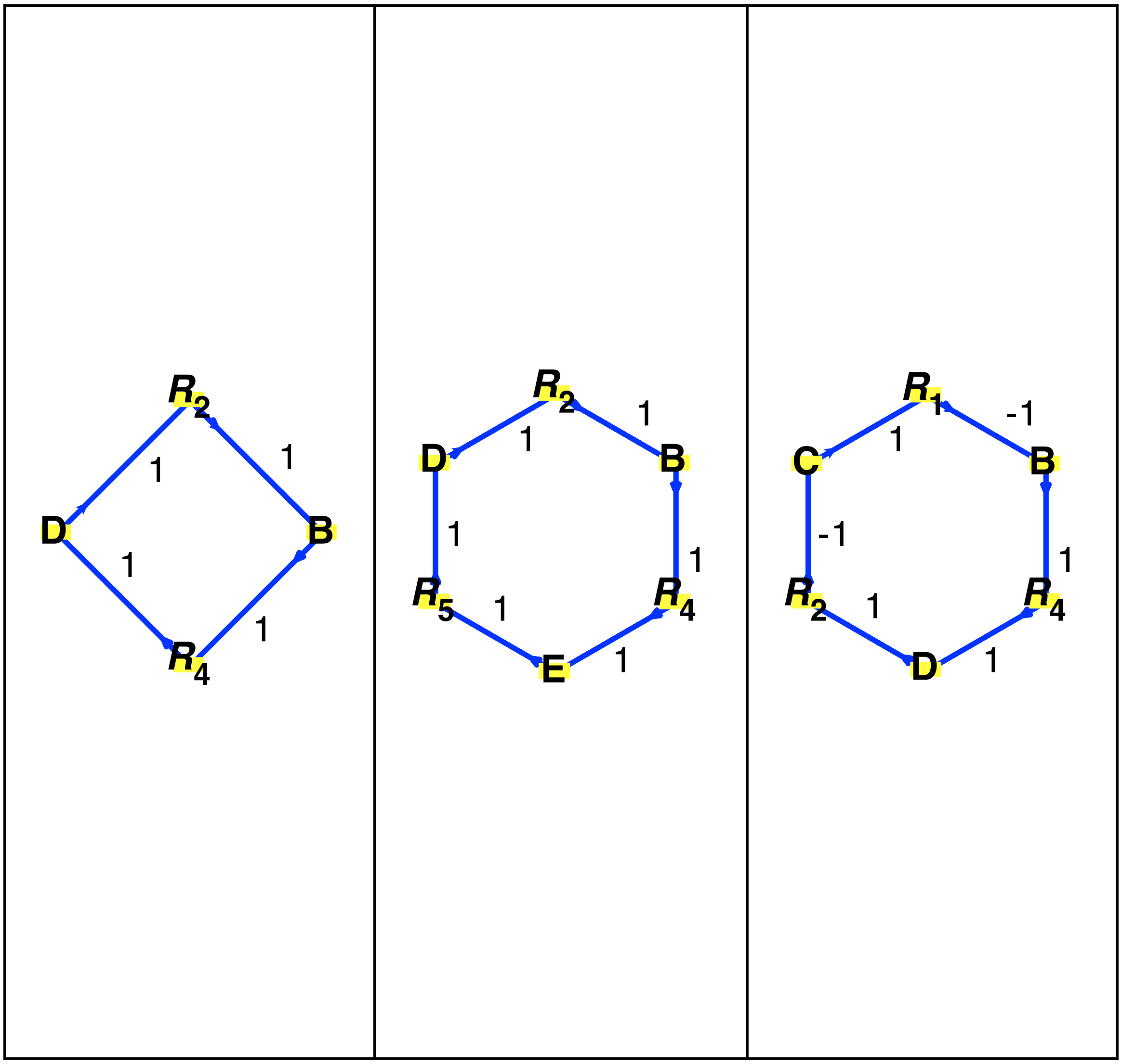
Meet both (?). NB: B, D, A are three states and all go to A.

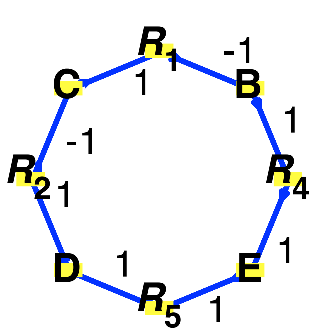
Network 2955 (meet neither, realistic but no futile cycle) three competing reactions

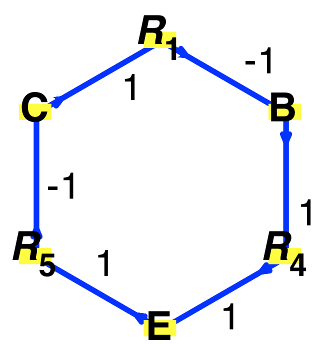
$B + C \rightarrow A$
$C + \mathrm{D} \rightarrow B$
$A \rightarrow B + C$
$B \rightarrow C + \mathrm{D}$
$C + E \rightarrow \mathrm{D}$

> $A := ImportMatrix(cat(uniquefolder, \text{"/injectiveEx3\_2955.csv"})); Z := findZ(A) :$
$selected := findloops(A, Z) : drawloops(selected, speciesord)$

$$A := \begin{bmatrix} 1 & 0 & -1 & 0 & 0 \\ -1 & 1 & 1 & -1 & 0 \\ -1 & -1 & 1 & 0 & -1 \\ 0 & -1 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 & -1 \end{bmatrix}$$







>

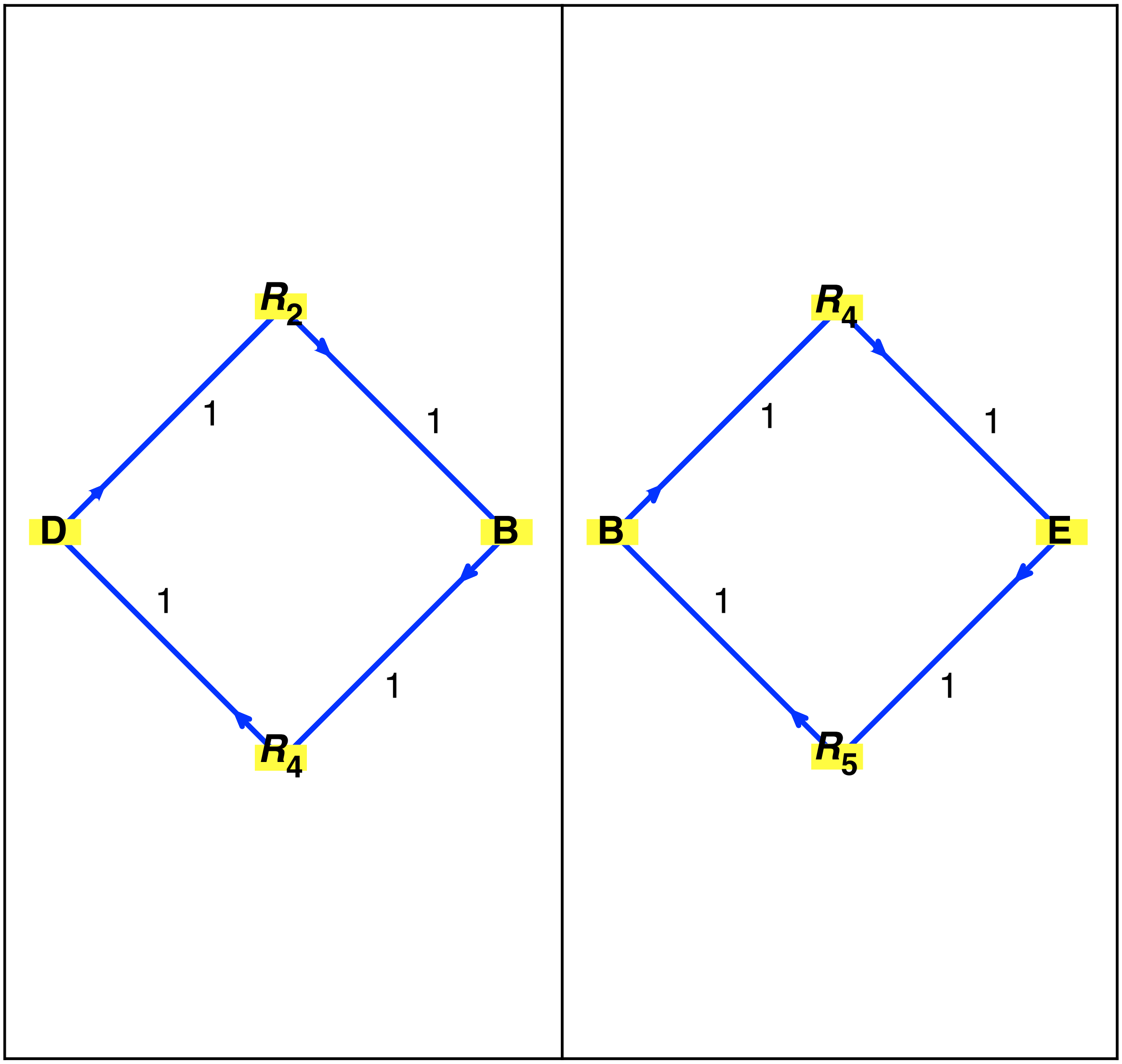
Meet condition 1 (?). NB: this is just complex formation, no futile cycles at all.

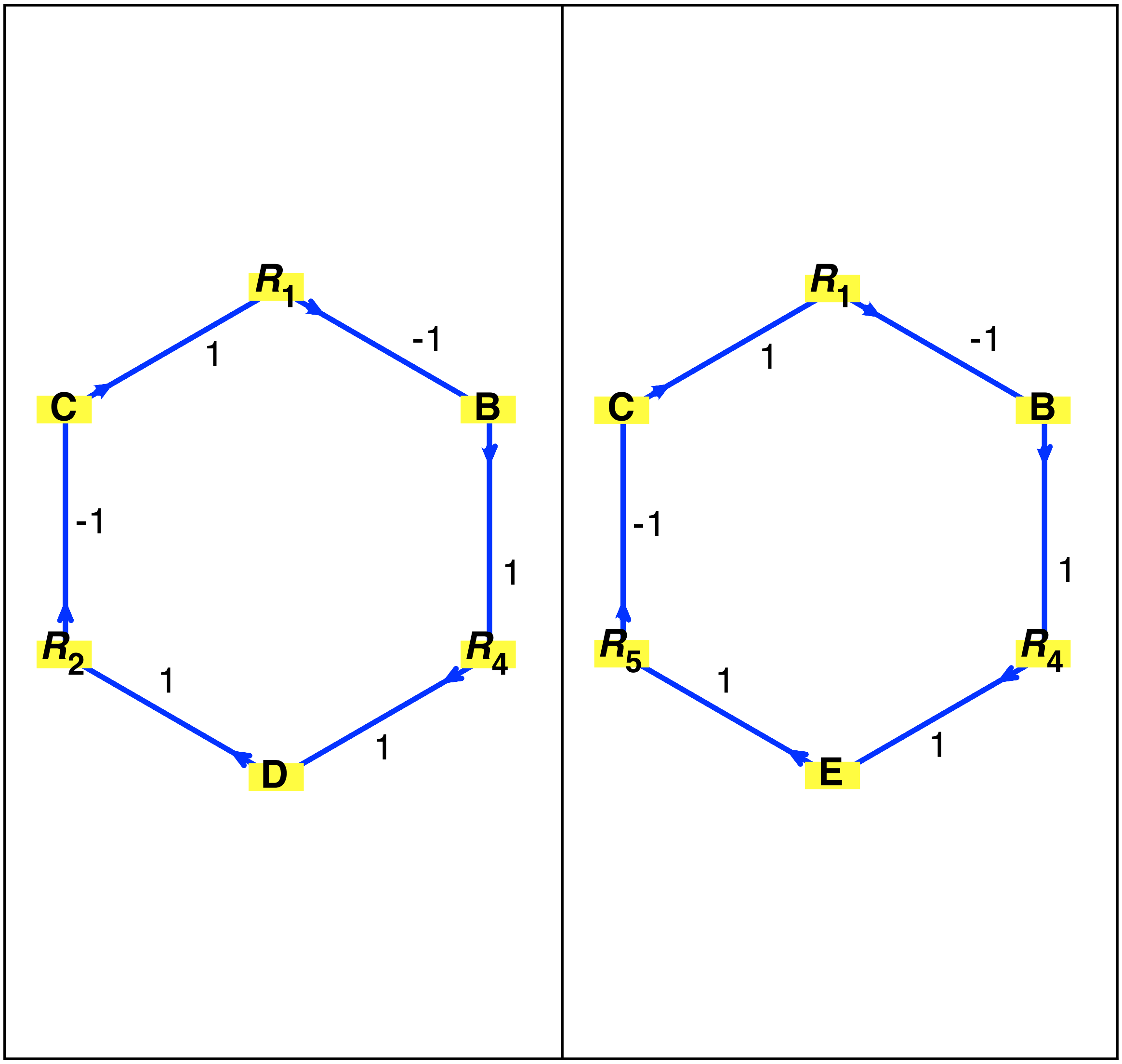
Network 2957 (meet neither, not realistic)

$B + C \rightarrow A$
$C + \mathrm{D} \rightarrow B$
$A \rightarrow B + C$
$B \rightarrow \mathrm{D} + E$
$C + E \rightarrow B$

```
> A := ImportMatrix(cat(uniquefolder, "/injectiveEx3_2957.csv")); Z := findZ(A) :
    selected := findloops(A, Z) : drawloops(selected, speciesord)
```

$$A := \begin{bmatrix} 1 & 0 & -1 & 0 & 0 \\ -1 & 1 & 1 & -1 & 1 \\ -1 & -1 & 1 & 0 & -1 \\ 0 & -1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & -1 \end{bmatrix}$$





>

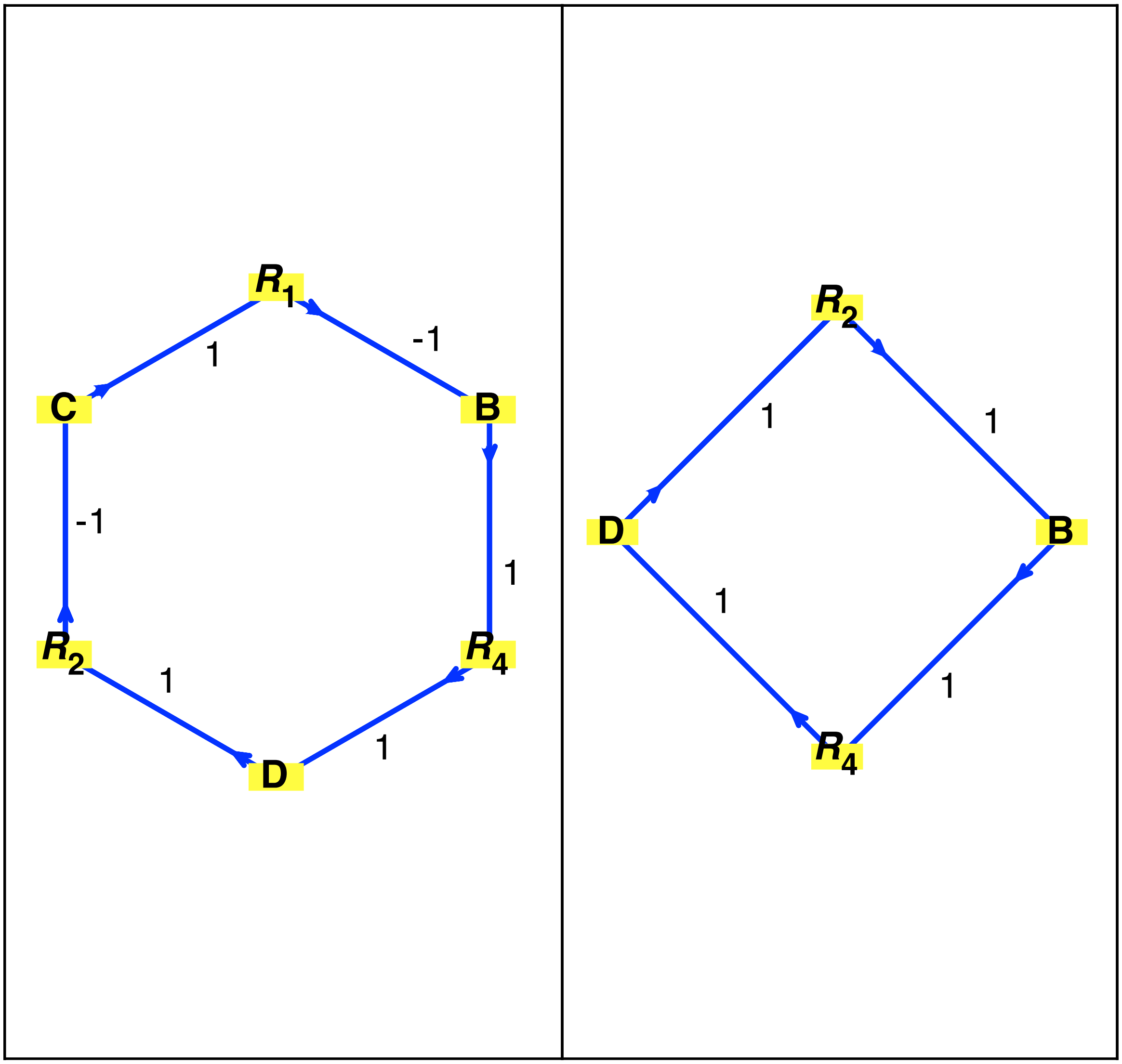
Meet both (?). NB: D is same as E!

Network 2958 (meet both condition 1 & 2, not realistic) three competing reactions

$B + C \to A$
$C + \mathrm{D} \to B$
$A \to B + C$
$B \to \mathrm{D} + E$
$\mathrm{D} + E \to B$

> $A := \mathit{ImportMatrix}(\mathit{cat}(\mathit{uniquefolder}, \text{"/injectiveEx3\_2958.csv"})); Z := \mathit{findZ}(A) :$
> $\mathit{selected} := \mathit{findloops}(A, Z) : \mathit{drawloops}(\mathit{selected}, \mathit{speciesord})$

$$A := \begin{bmatrix} 1 & 0 & -1 & 0 & 0 \\ -1 & 1 & 1 & -1 & 1 \\ -1 & -1 & 1 & 0 & 0 \\ 0 & -1 & 0 & 1 & -1 \\ 0 & 0 & 0 & 1 & -1 \end{bmatrix}$$



>

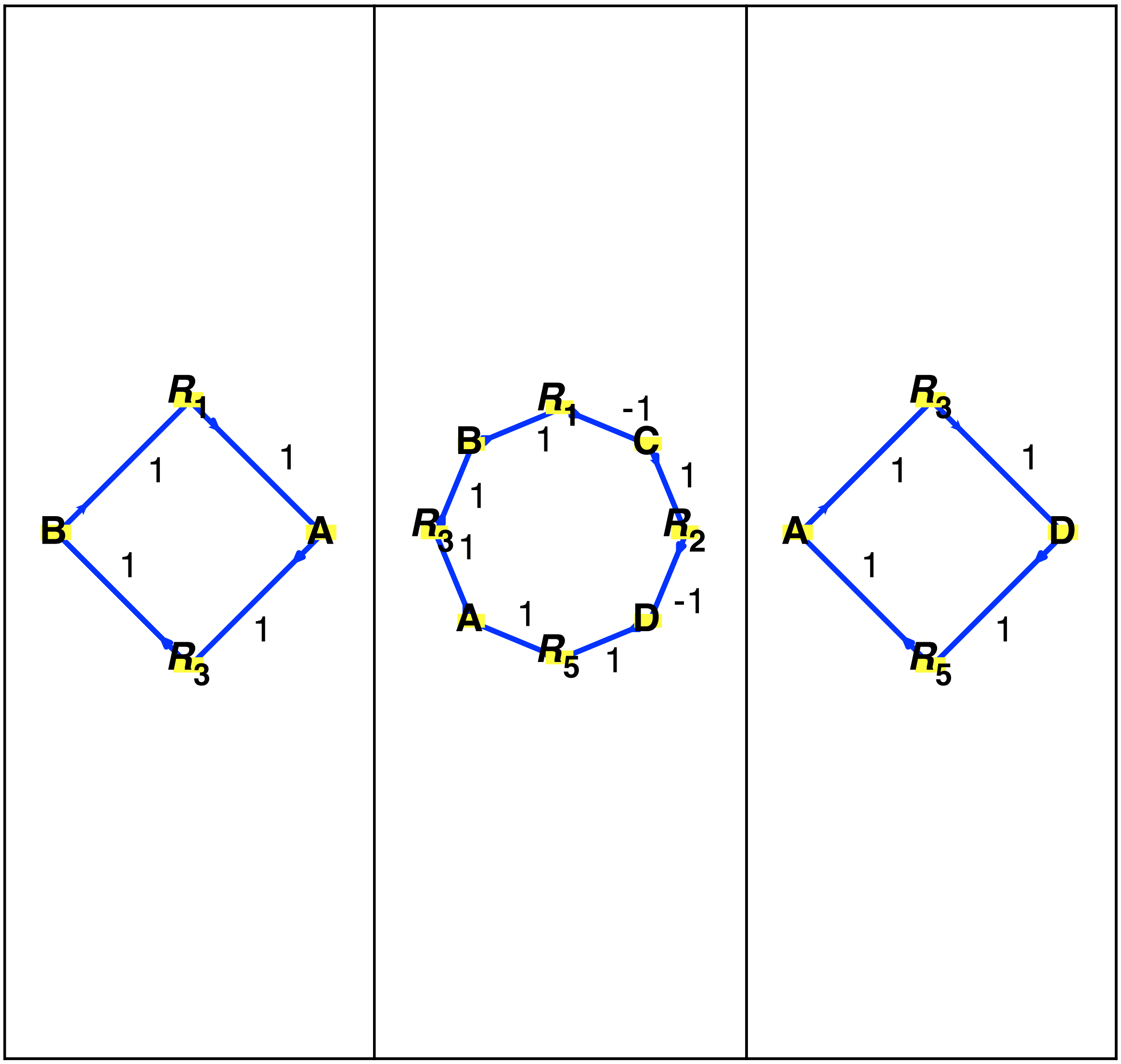
Meet both conditions. NB: E is same as C.

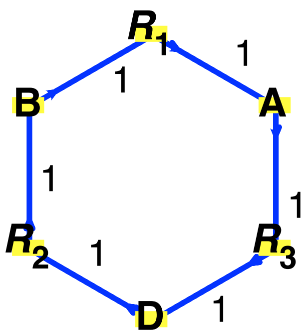
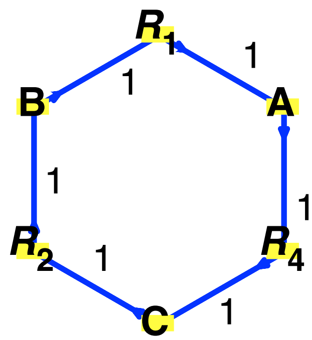
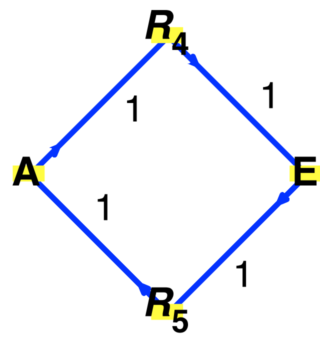
Network 2965 (meet neither, not realistic) three competing reactions

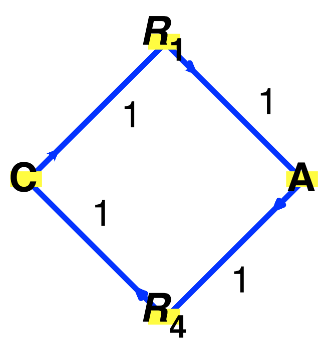
$B + C \rightarrow A$
$C + \mathrm{D} \rightarrow B$
$A \rightarrow B + \mathrm{D}$
$A \rightarrow C + E$
$\mathrm{D} + E \rightarrow A$

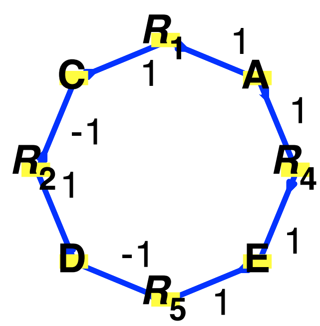
> $A := ImportMatrix(cat(uniquefolder, \text{"/injectiveEx3\_2965.csv"})); Z := findZ(A):$
$selected := findloops(A, Z) : drawloops(selected, speciesord)$

$$A := \begin{bmatrix} 1 & 0 & -1 & -1 & 1 \\ -1 & 1 & 1 & 0 & 0 \\ -1 & -1 & 0 & 1 & 0 \\ 0 & -1 & 1 & 0 & -1 \\ 0 & 0 & 0 & 1 & -1 \end{bmatrix}$$



 R_1 B A R_2 R_3 D 1	 R_1 B A R_2 R_4 C 1	 R_4 A E R_5 1





>

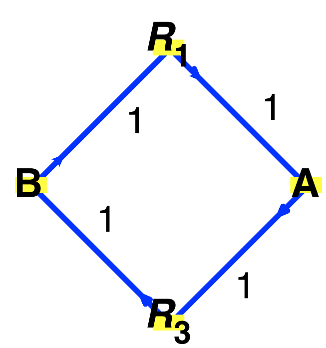
Meet both (?). NB: A is trimer, B & E are dimers of C & D, B catalyze C to D, C catalyze B to E.

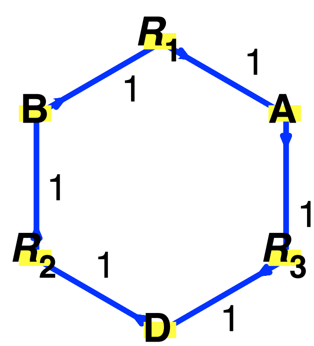
Network 2969 (meet neither, not realistic) three competing reactions

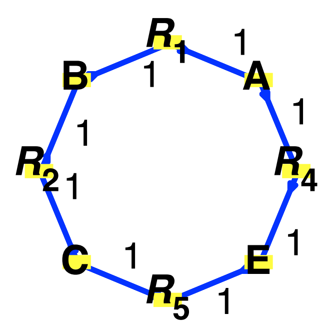
$B + C \rightarrow A$
$C + \mathrm{D} \rightarrow B$
$A \rightarrow B + \mathrm{D}$
$A + \mathrm{D} \rightarrow E$
$E \rightarrow A + C$

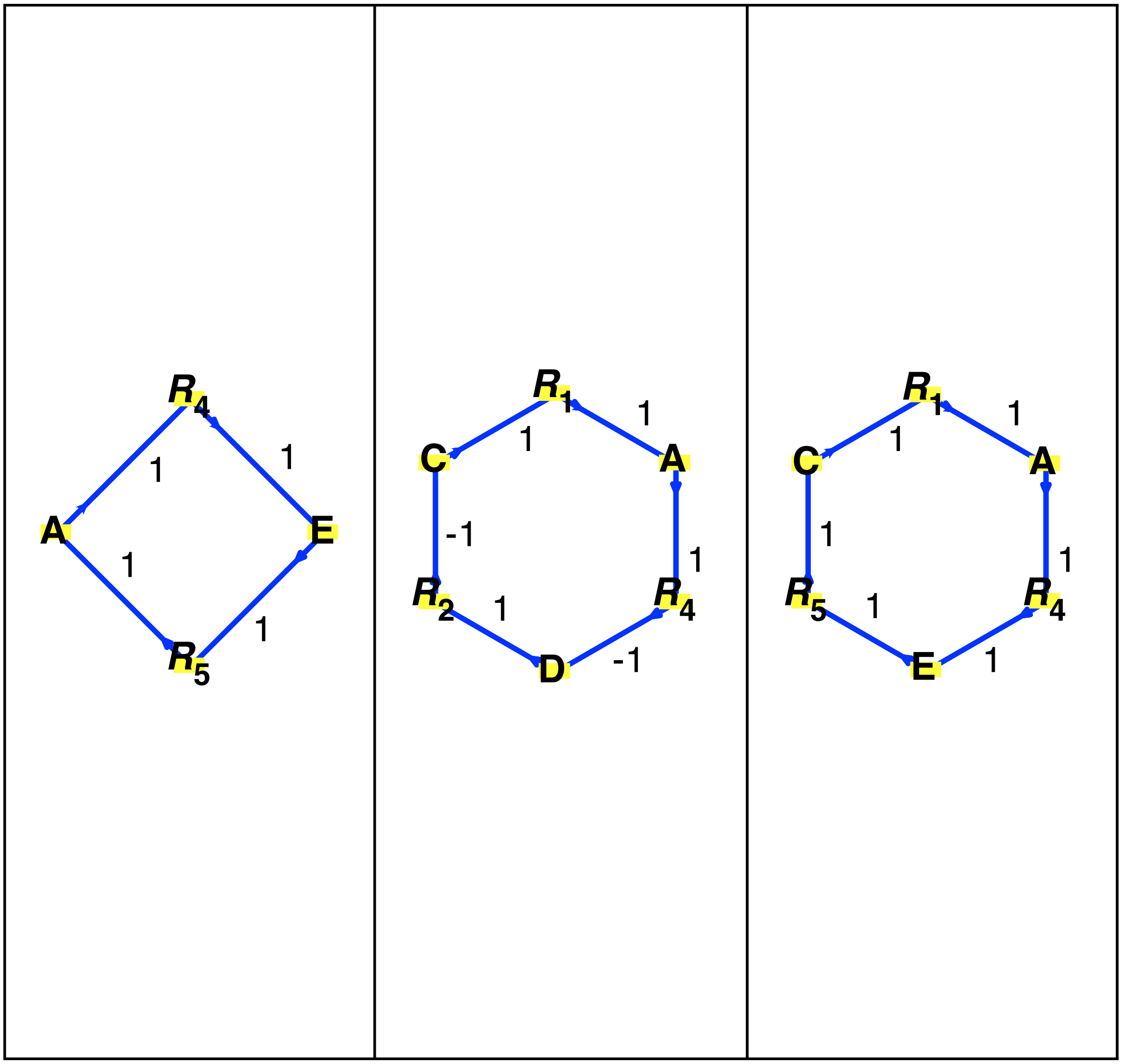
> $A := \mathit{ImportMatrix}(\mathit{cat}(\mathit{uniquefolder}, \text{"/injectiveEx3\_2969.csv"})); Z := \mathit{findZ}(A) :$
> $\mathit{selected} := \mathit{findloops}(A, Z) : \mathit{drawloops}(\mathit{selected}, \mathit{speciesord})$

$$A := \begin{bmatrix} 1 & 0 & -1 & -1 & 1 \\ -1 & 1 & 1 & 0 & 0 \\ -1 & -1 & 0 & 0 & 1 \\ 0 & -1 & 1 & -1 & 0 \\ 0 & 0 & 0 & 1 & -1 \end{bmatrix}$$









>

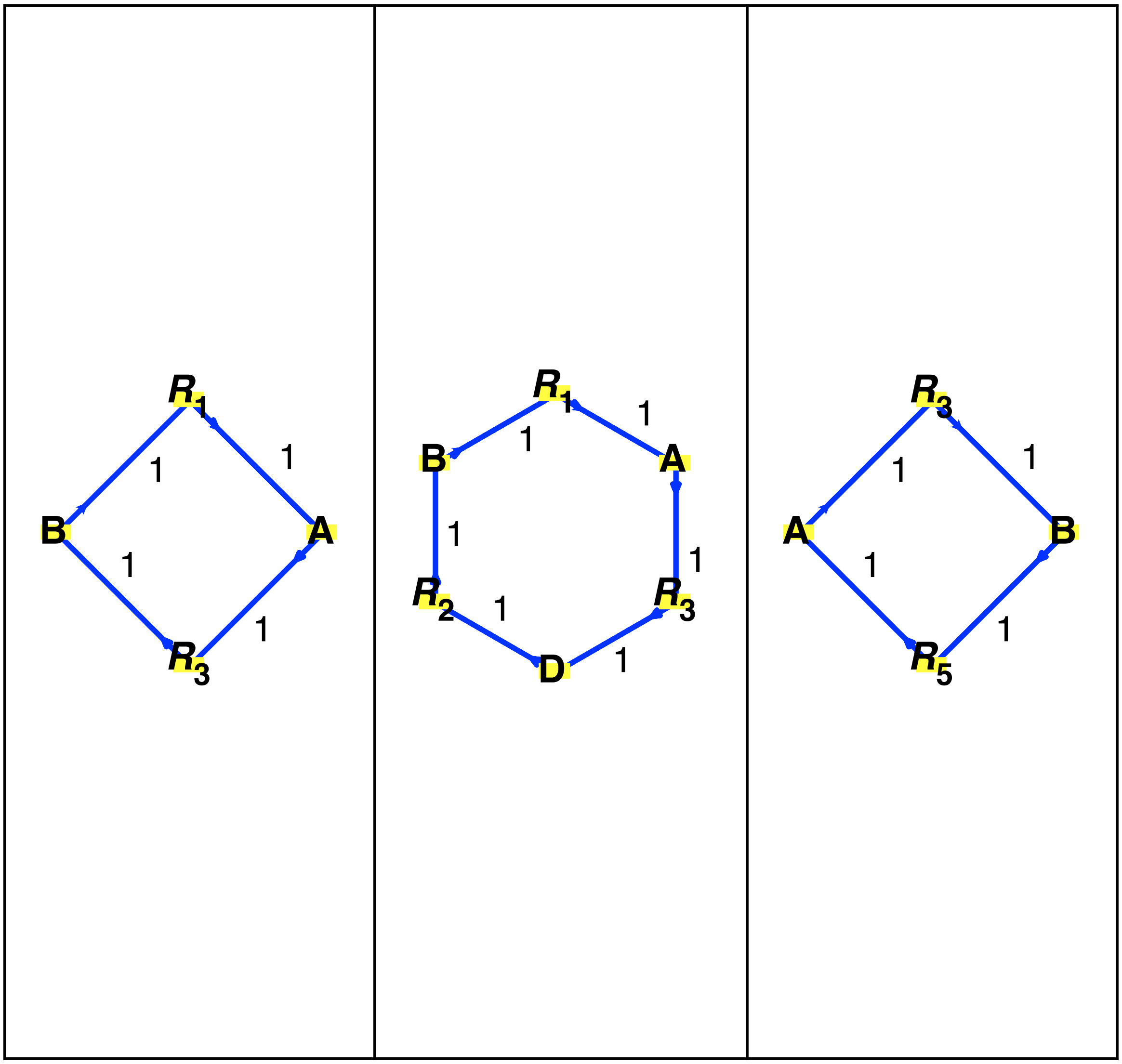
Meet both (?). NB: D is tetramer, A is trimer, B is dimer of C & D, B catalyze C to D, A catalyze D to C.

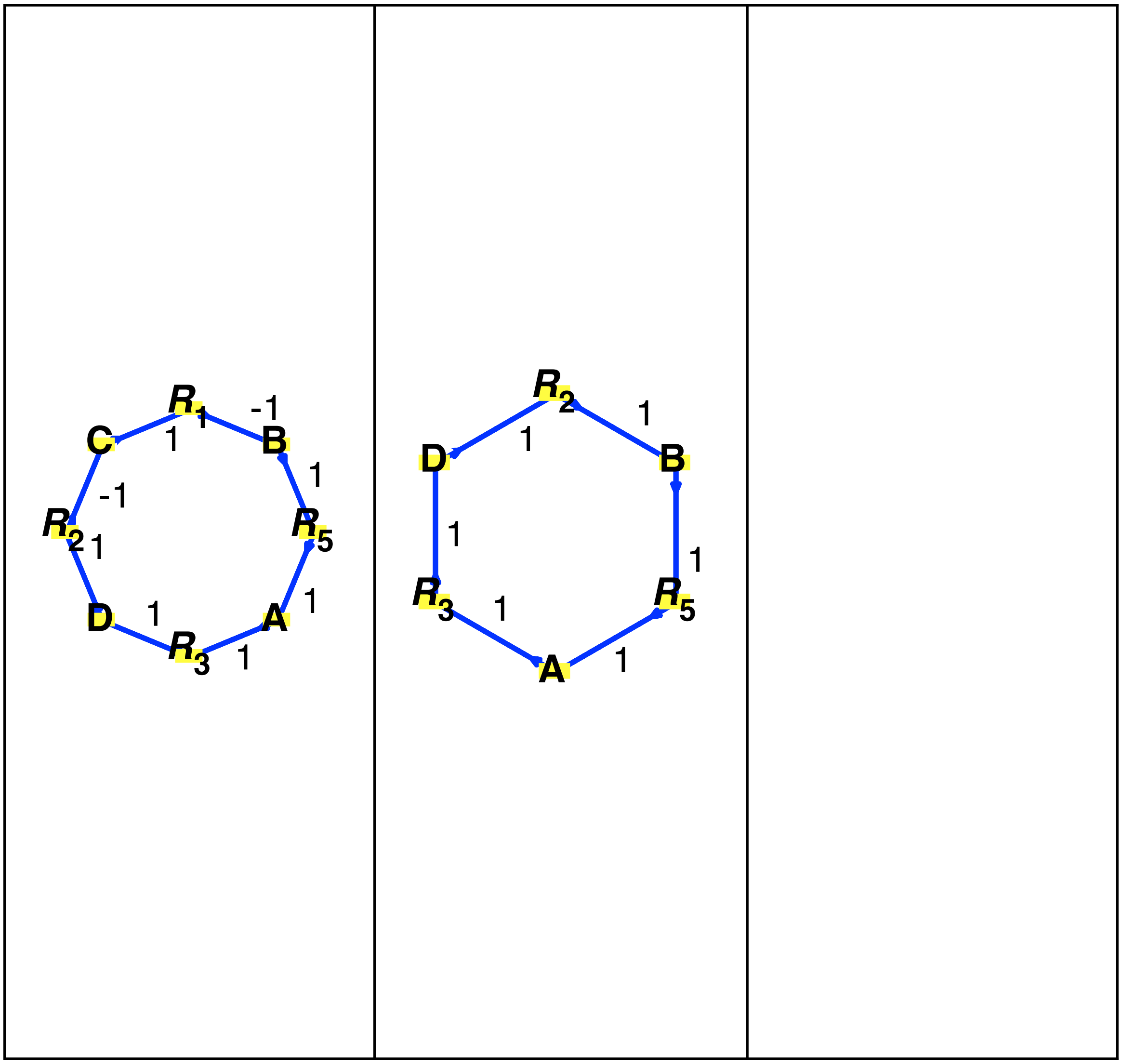
Network 2970 (meet neither, maybe not realistic) three competing reactions

$B + C \rightarrow A$
$C + \mathrm{D} \rightarrow B$
$A \rightarrow B + \mathrm{D}$
$B \rightarrow C + E$
$E + B \rightarrow A$

```
> A := ImportMatrix(cat(uniquefolder, "/injectiveEx3_2970.csv")); Z := findZ(A) :
    selected := findloops(A, Z) : drawloops(selected, speciesord)
```

$$A := \begin{bmatrix} 1 & 0 & -1 & 0 & 1 \\ -1 & 1 & 1 & -1 & -1 \\ -1 & -1 & 0 & 1 & 0 \\ 0 & -1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & -1 \end{bmatrix}$$





>

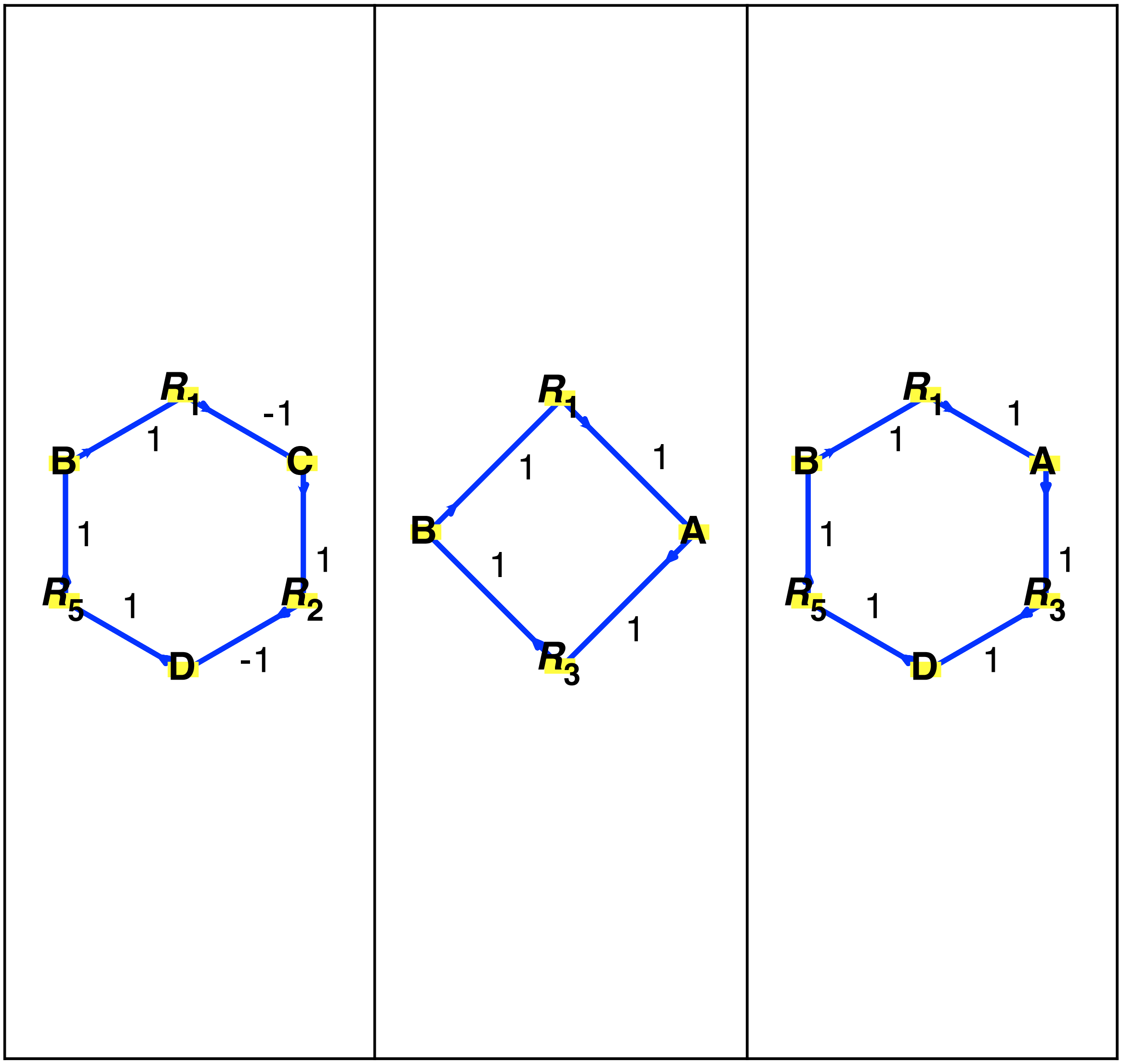
Meet both (?). NB: A is trimer, B is dimer of C, D & E, B catalyze C to D, C catalyze D to E.

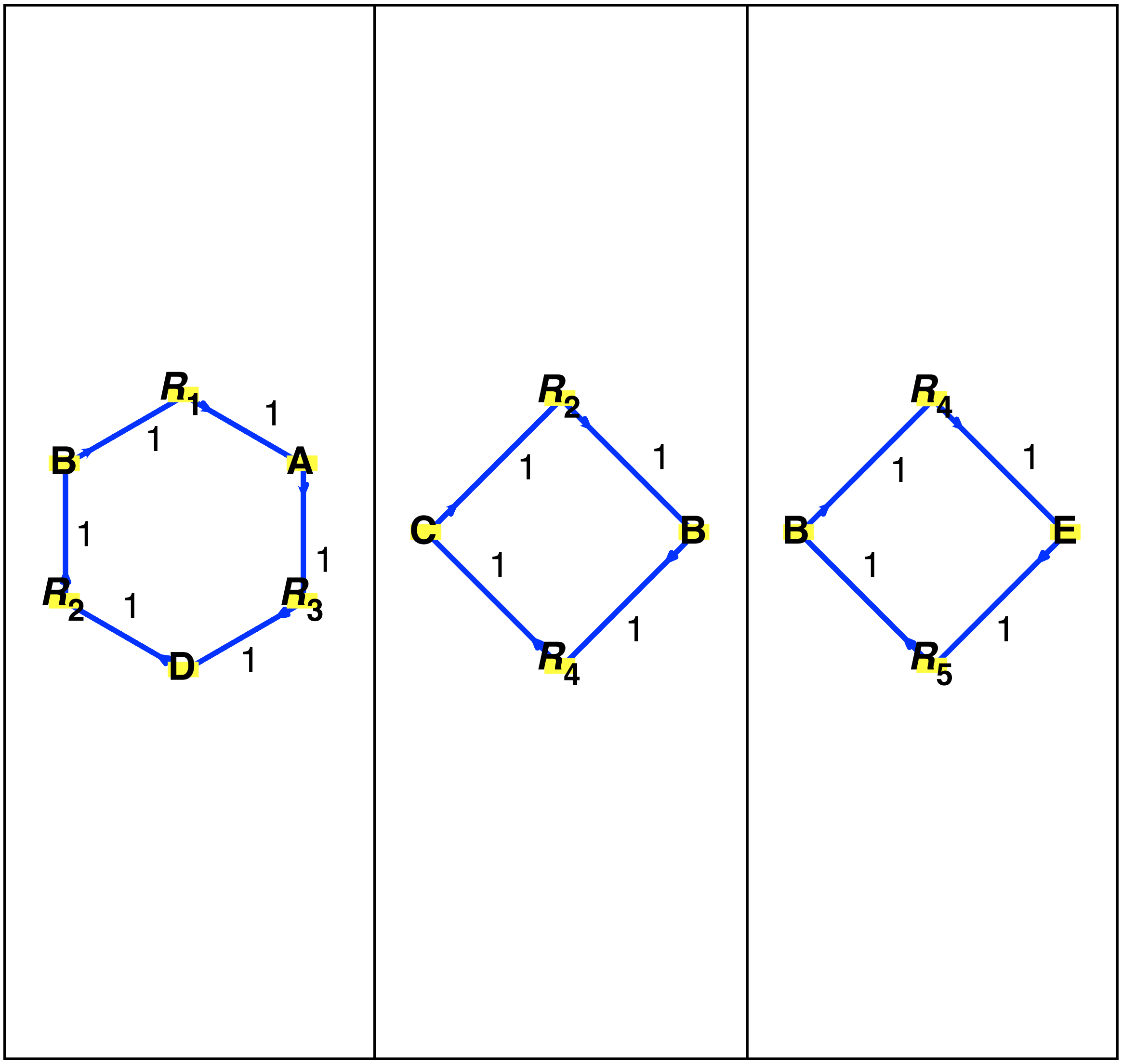
Network 2972 (meet neither, maybe not realistic) three competing reactions

$B + C \rightarrow A$
$C + \mathrm{D} \rightarrow B$
$A \rightarrow B + \mathrm{D}$
$B \rightarrow C + E$
$E + \mathrm{D} \rightarrow B$

> $A := ImportMatrix(cat(uniquefolder, \text{"/injectiveEx3\_2972.csv"})); Z := findZ(A) : selected := findloops(A, Z) : drawloops(selected, speciesord)$

$$A := \begin{bmatrix} 1 & 0 & -1 & 0 & 0 \\ -1 & 1 & 1 & -1 & 1 \\ -1 & -1 & 0 & 1 & 0 \\ 0 & -1 & 1 & 0 & -1 \\ 0 & 0 & 0 & 1 & -1 \end{bmatrix}$$





>

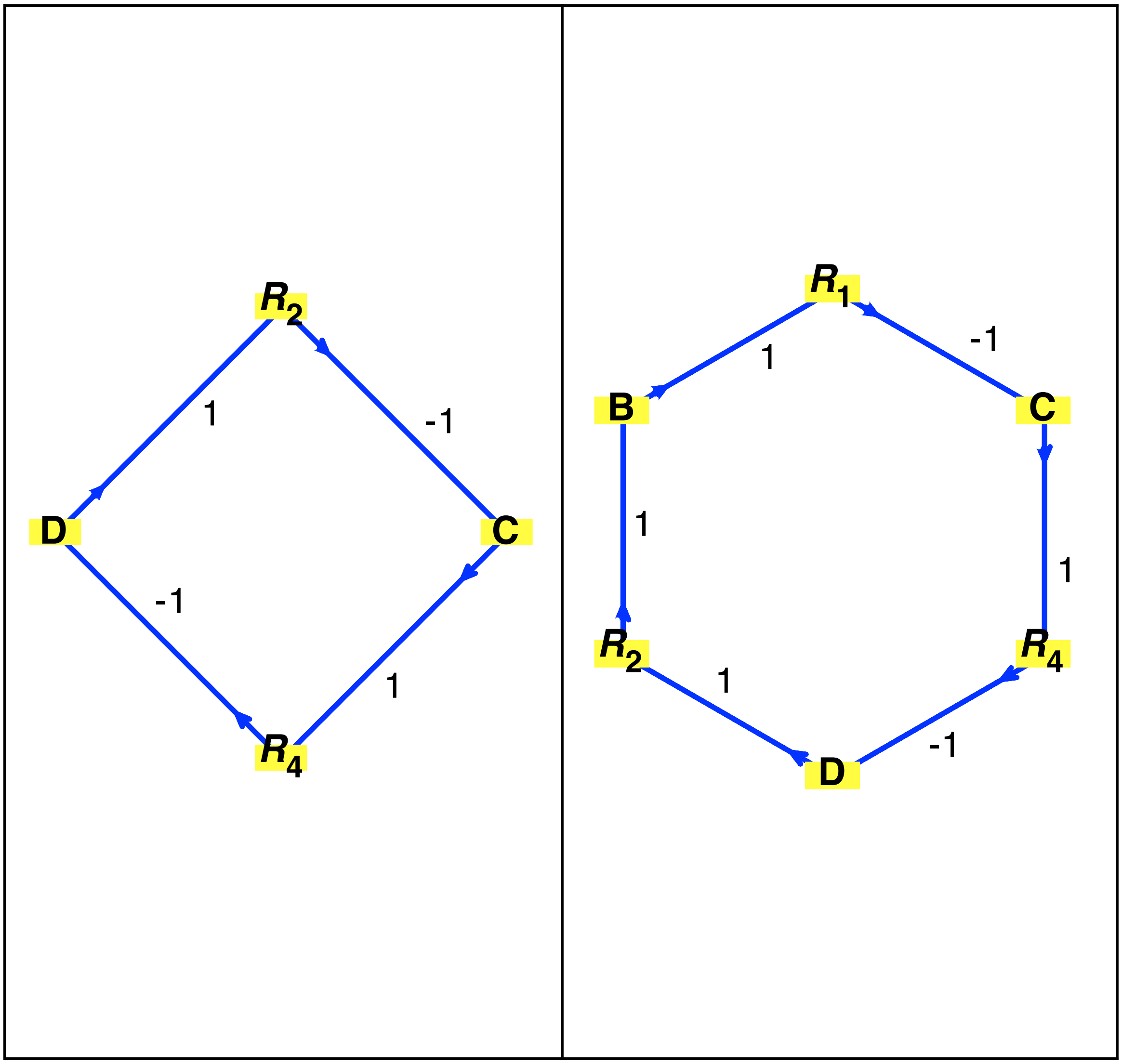
Meet both (?). NB: A is trimer, B is dimer of C, D & E, B catalyze C to D, C catalyze D to E.

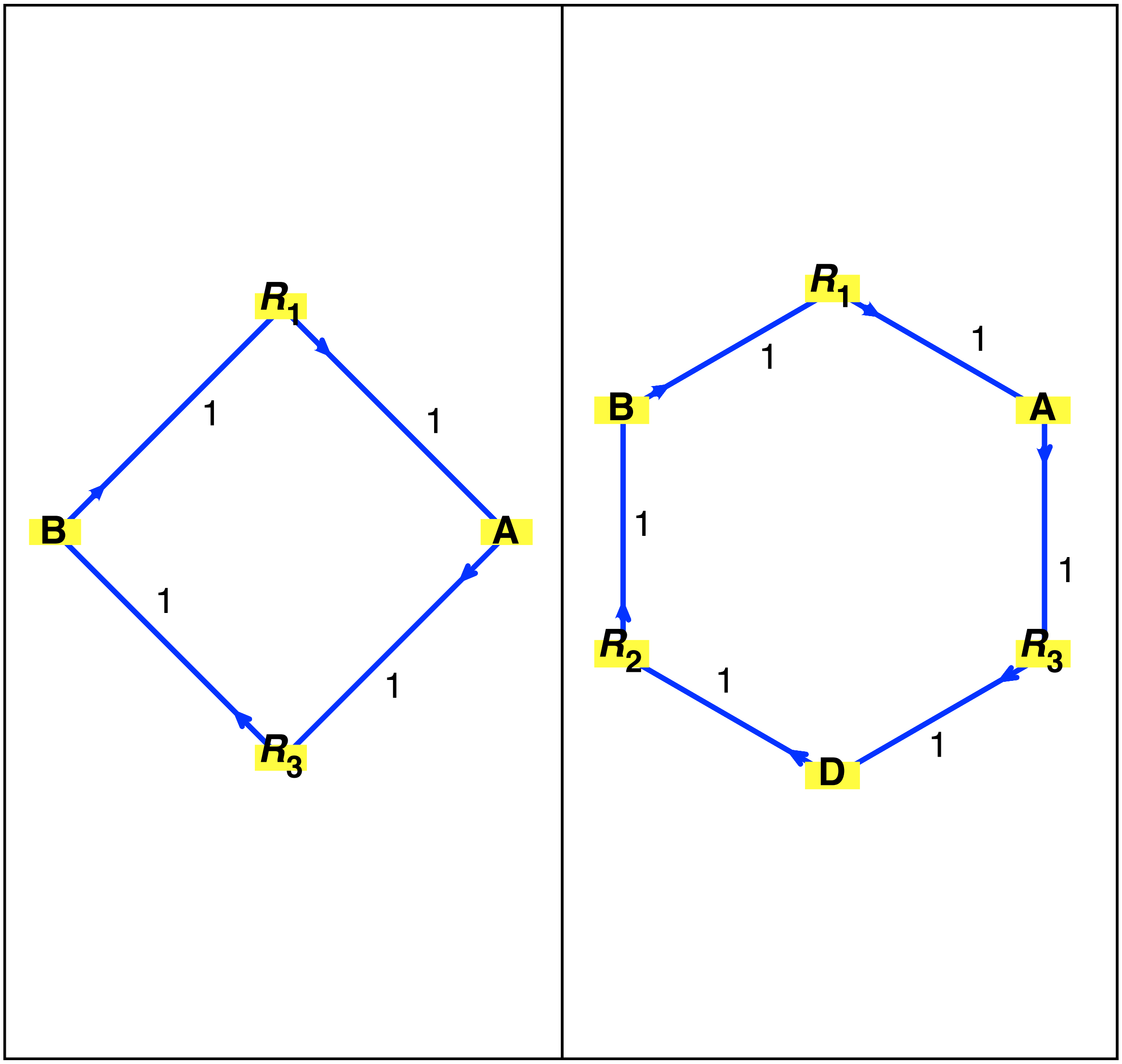
Network 2975 (meet neither, not realistic) three competing reactions

$B + C \rightarrow A$
$C + \mathrm{D} \rightarrow B$
$A \rightarrow B + \mathrm{D}$
$C + \mathrm{D} \rightarrow E$
$E \rightarrow C + \mathrm{D}$

> $A := ImportMatrix(cat(uniquefolder,$ "/injectiveEx3_2975.csv"$))$; $Z := findZ(A)$: $selected := findloops(A, Z)$: $drawloops(selected, speciesord)$

$$A := \begin{bmatrix} 1 & 0 & -1 & 0 & 0 \\ -1 & 1 & 1 & 0 & 0 \\ -1 & -1 & 0 & -1 & 1 \\ 0 & -1 & 1 & -1 & 1 \\ 0 & 0 & 0 & 1 & -1 \end{bmatrix}$$





>

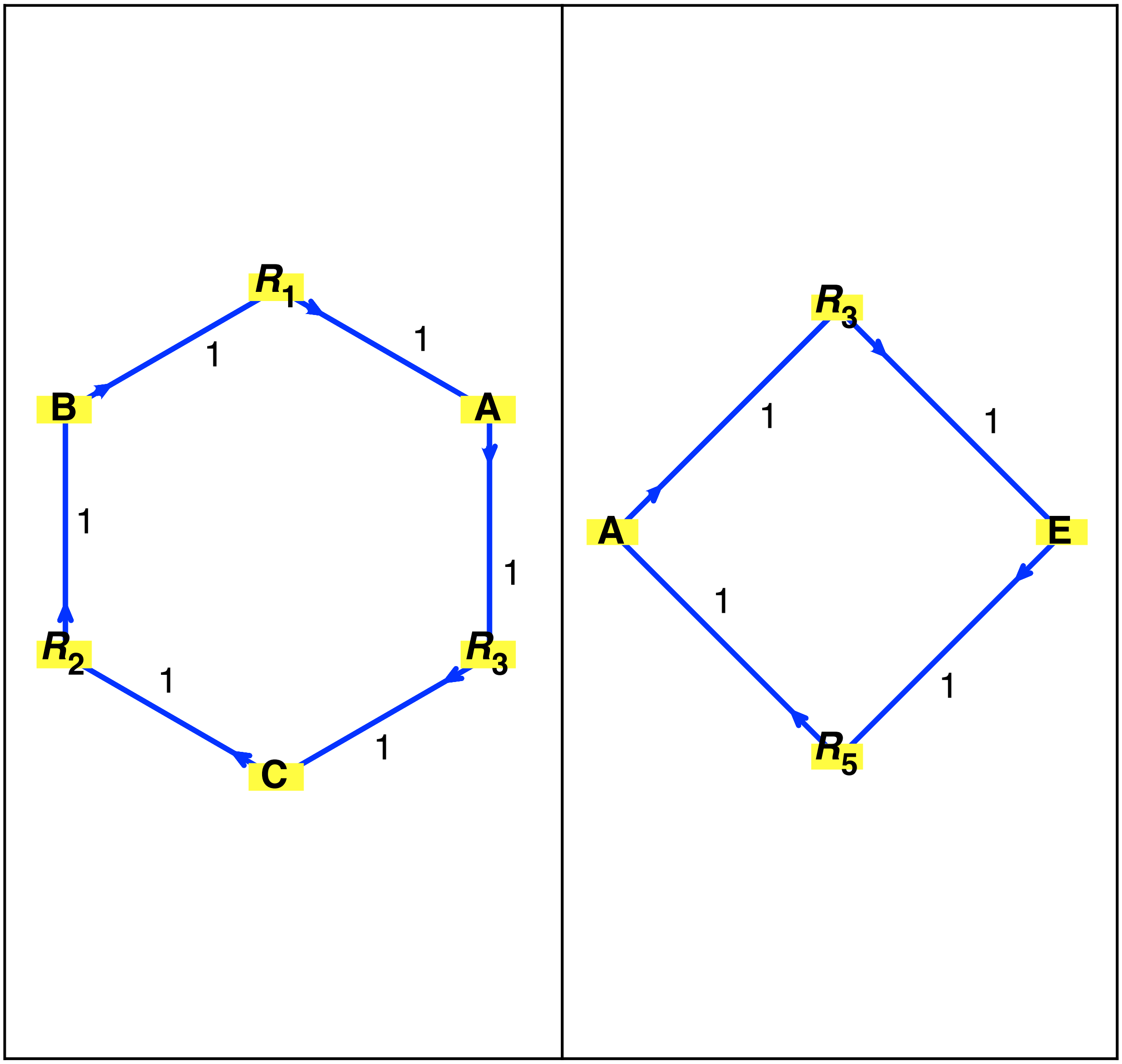
Meet both (?). NB: E is same as B.

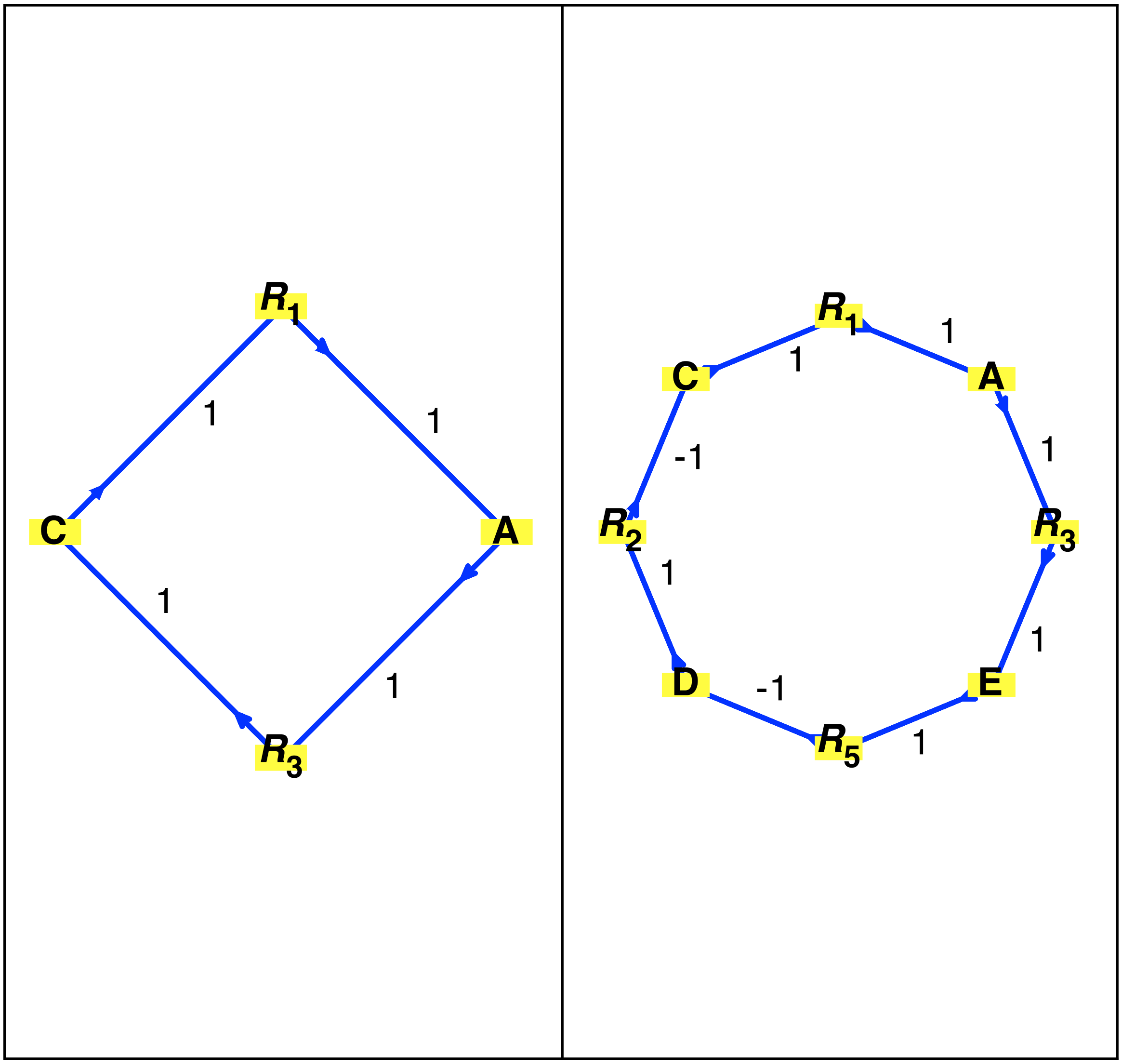
Network 2983 (meet neither, not realistic) three competing reactions

$B + C \rightarrow A$
$C + \mathrm{D} \rightarrow B$
$A \rightarrow C + E$
$A \rightarrow \mathrm{D} + E$
$E + \mathrm{D} \rightarrow A$

> $A := ImportMatrix(cat(uniquefolder, \text{"/injectiveEx3\_2983.csv"}));$ $Z := findZ(A):$ $selected := findloops(A, Z) : drawloops(selected, speciesord)$

$$A := \begin{bmatrix} 1 & 0 & -1 & -1 & 1 \\ -1 & 1 & 0 & 0 & 0 \\ -1 & -1 & 1 & 0 & 0 \\ 0 & -1 & 0 & 1 & -1 \\ 0 & 0 & 1 & 1 & -1 \end{bmatrix}$$





>

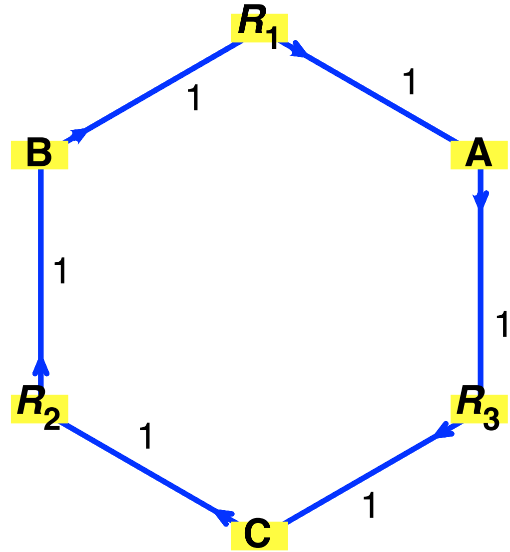
Meet both (?). NB: C is same as D.

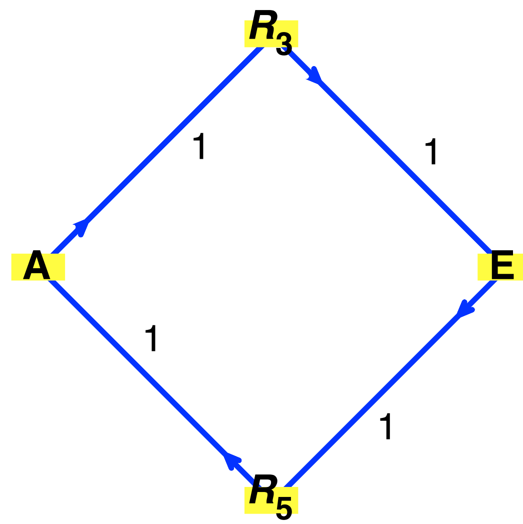
Network 2986 (meet neither, not realistic) three competing reactions

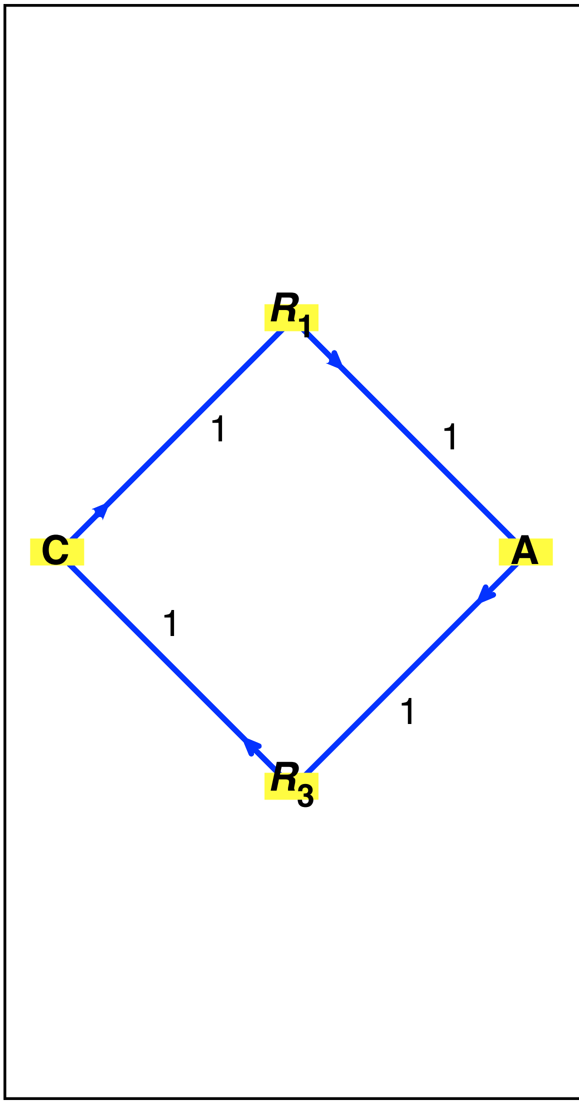
$B + C \rightarrow A$
$C + \mathrm{D} \rightarrow B$
$A \rightarrow C + E$
$B \rightarrow C + \mathrm{D}$
$E + \mathrm{D} \rightarrow A$

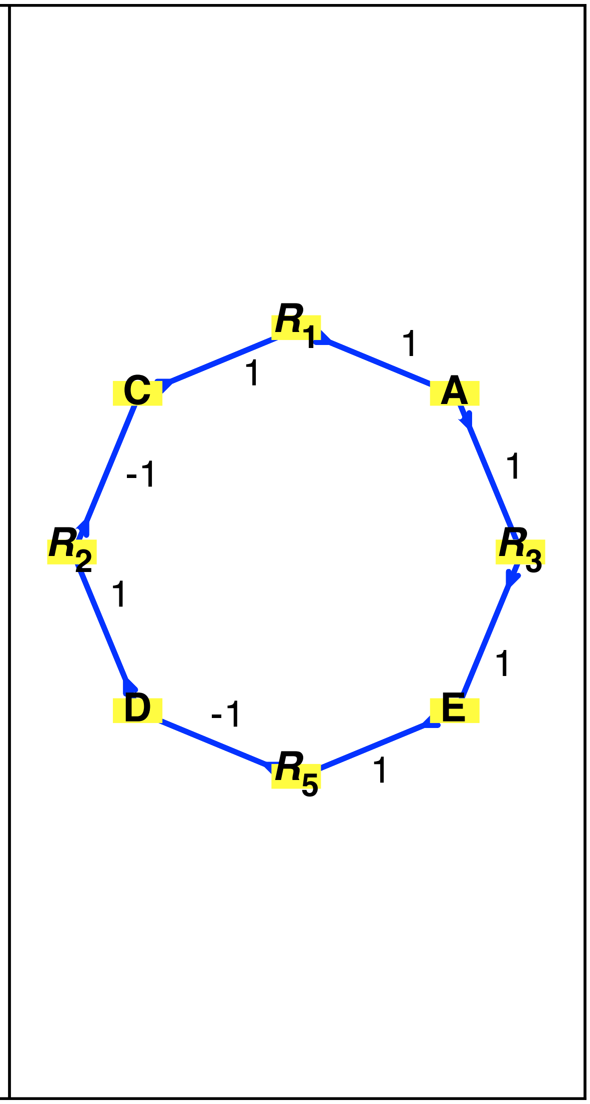
> $A := ImportMatrix(cat(uniquefolder, \text{"/injectiveEx3\_2986.csv"}));$ $Z := findZ(A)$: $selected := findloops(A, Z)$: $drawloops(selected, speciesord)$

$$A := \begin{bmatrix} 1 & 0 & -1 & 0 & 1 \\ -1 & 1 & 0 & -1 & 0 \\ -1 & -1 & 1 & 1 & 0 \\ 0 & -1 & 0 & 1 & -1 \\ 0 & 0 & 1 & 0 & -1 \end{bmatrix}$$









>

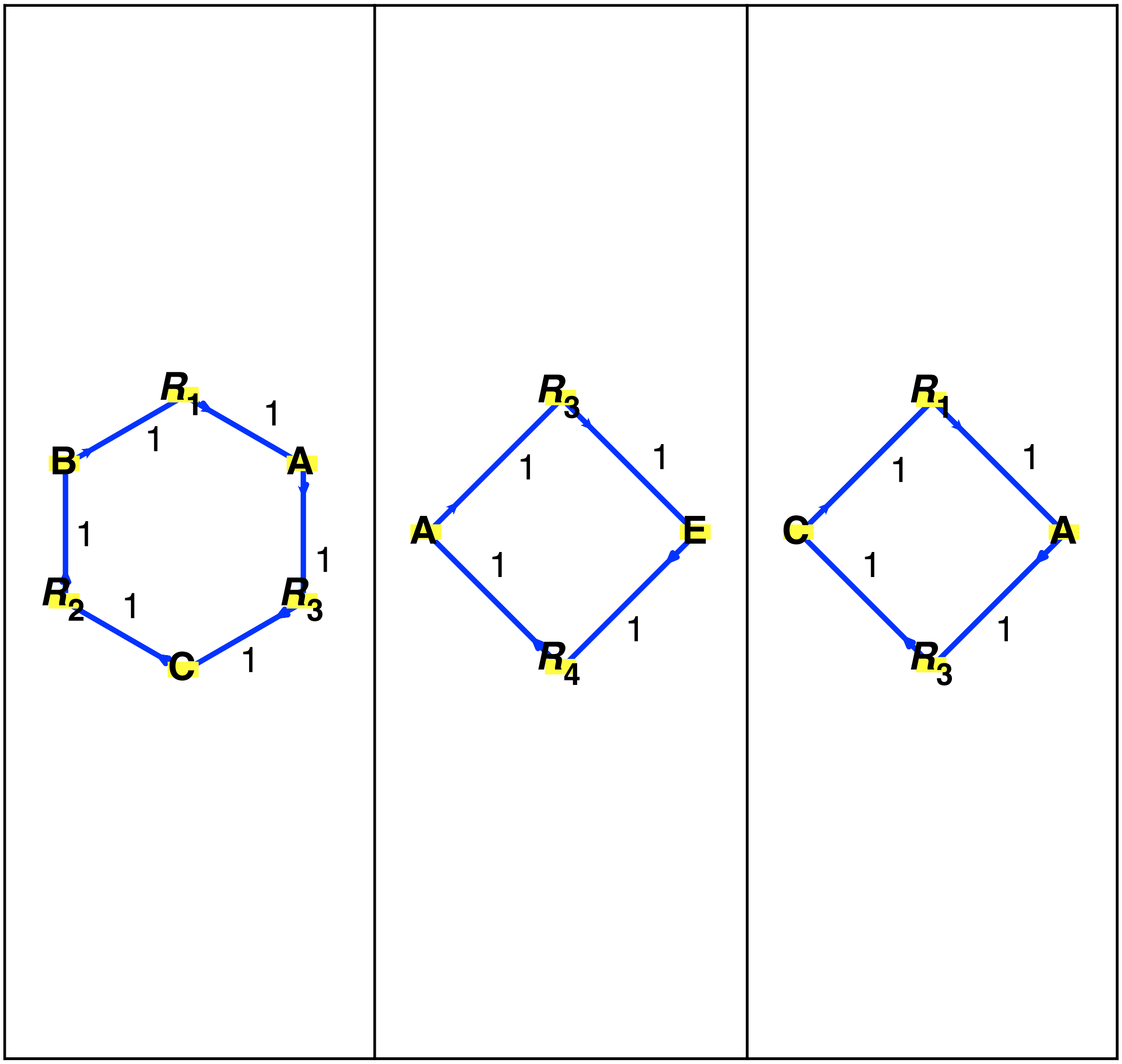
Meet both (?). NB: A is trimer, B & E are dimers of C & D, C catalyze B to E.

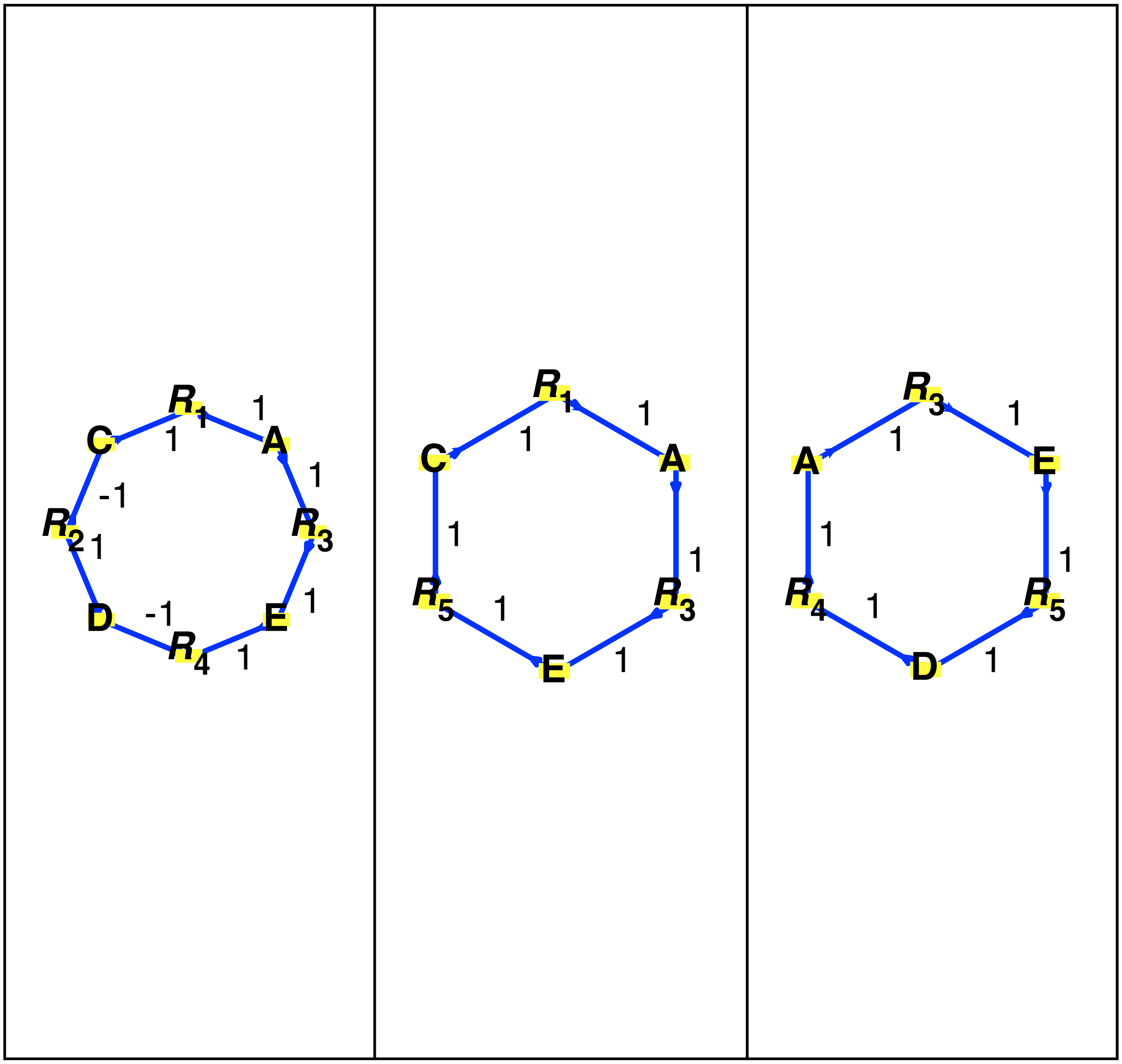
Network 2992 (meet neither, not realistic) three competing reactions

$B + C \rightarrow A$
$C + \mathrm{D} \rightarrow B$
$A \rightarrow C + E$
$E \rightarrow C + \mathrm{D}$
$E + \mathrm{D} \rightarrow A$

> $A := ImportMatrix(cat(uniquefolder, \text{"/injectiveEx3\_2992.csv"})); Z := findZ(A) :$
> $selected := findloops(A, Z) : drawloops(selected, speciesord)$

$$A := \begin{bmatrix} 1 & 0 & -1 & 1 & 0 \\ -1 & 1 & 0 & 0 & 0 \\ -1 & -1 & 1 & 0 & 1 \\ 0 & -1 & 0 & -1 & 1 \\ 0 & 0 & 1 & -1 & -1 \end{bmatrix}$$





>

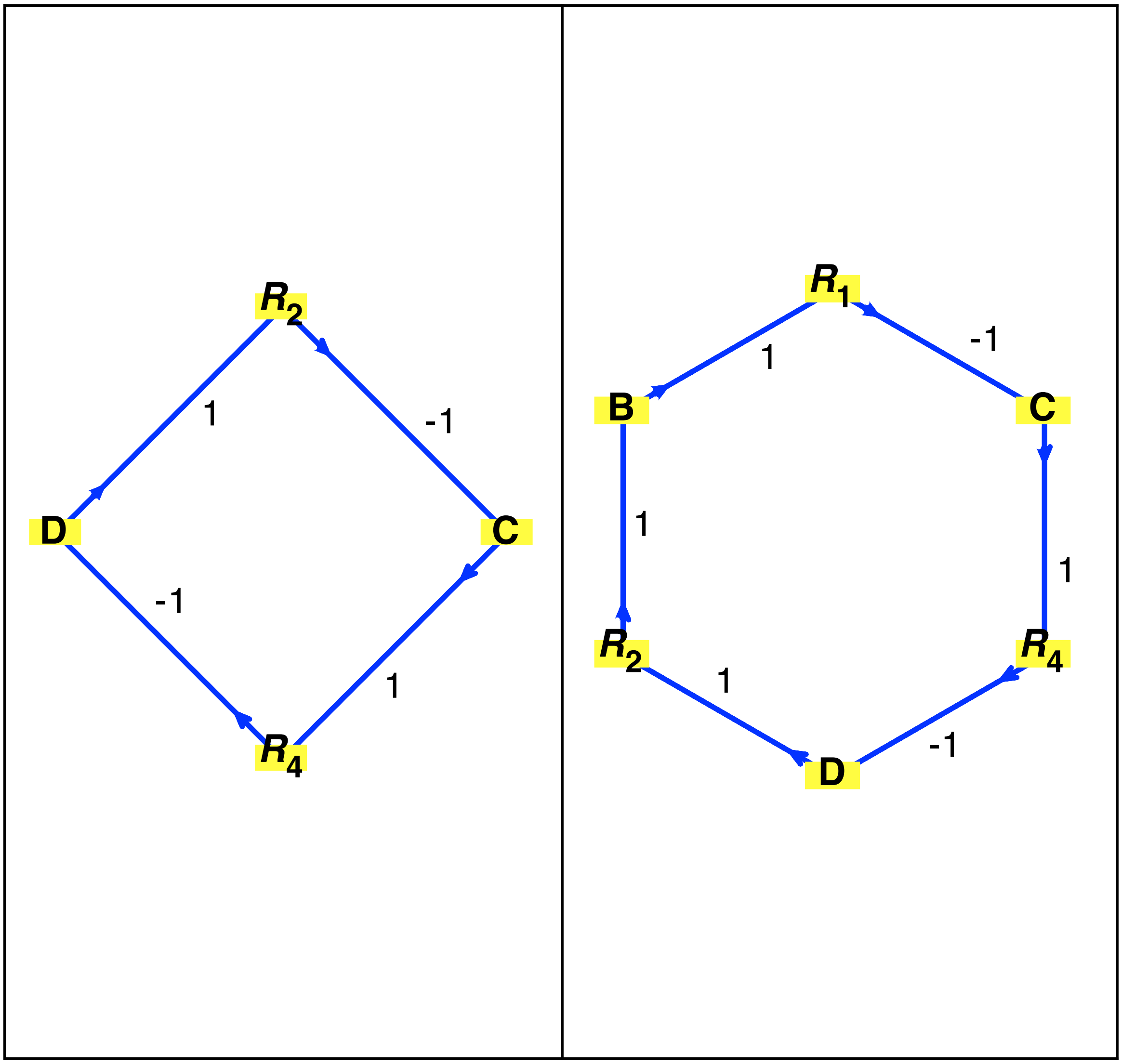
Meet both (?). NB: A is trimer, B & E are dimers of C & D, C catalyze B to E.

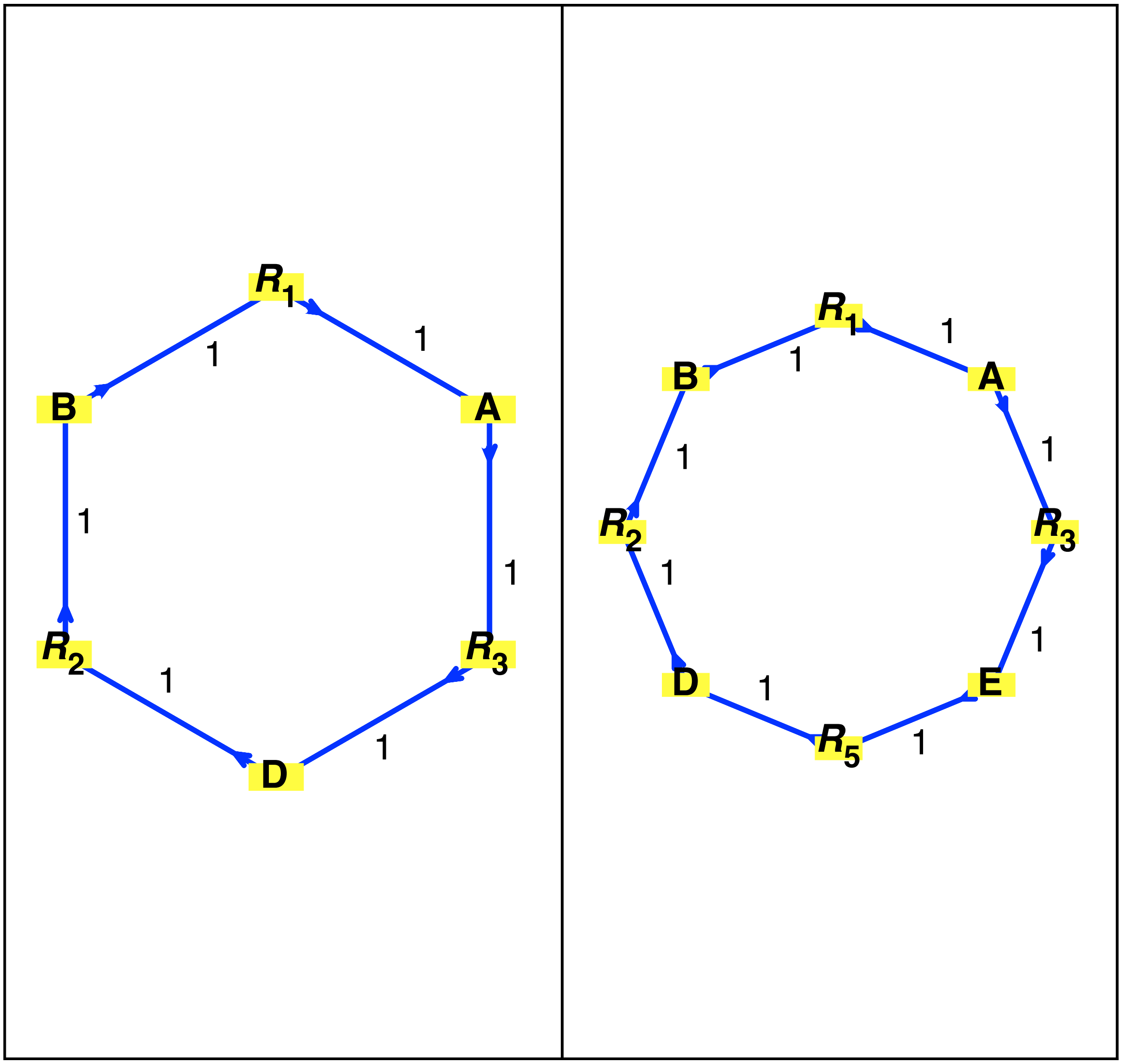
Network 3007 (meet neither, not realistic) three competing reactions

$B + C \rightarrow A$
$C + \mathrm{D} \rightarrow B$
$A \rightarrow \mathrm{D} + E$
$C + \mathrm{D} \rightarrow E$
$E \rightarrow C + \mathrm{D}$

```
> A := ImportMatrix(cat(uniquefolder, "/injectiveEx3_3007.csv")); Z := findZ(A) :
    selected := findloops(A, Z) : drawloops(selected, speciesord)
```

$$A := \begin{bmatrix} 1 & 0 & -1 & 0 & 0 \\ -1 & 1 & 0 & 0 & 0 \\ -1 & -1 & 0 & -1 & 1 \\ 0 & -1 & 1 & -1 & 1 \\ 0 & 0 & 1 & 1 & -1 \end{bmatrix}$$





>

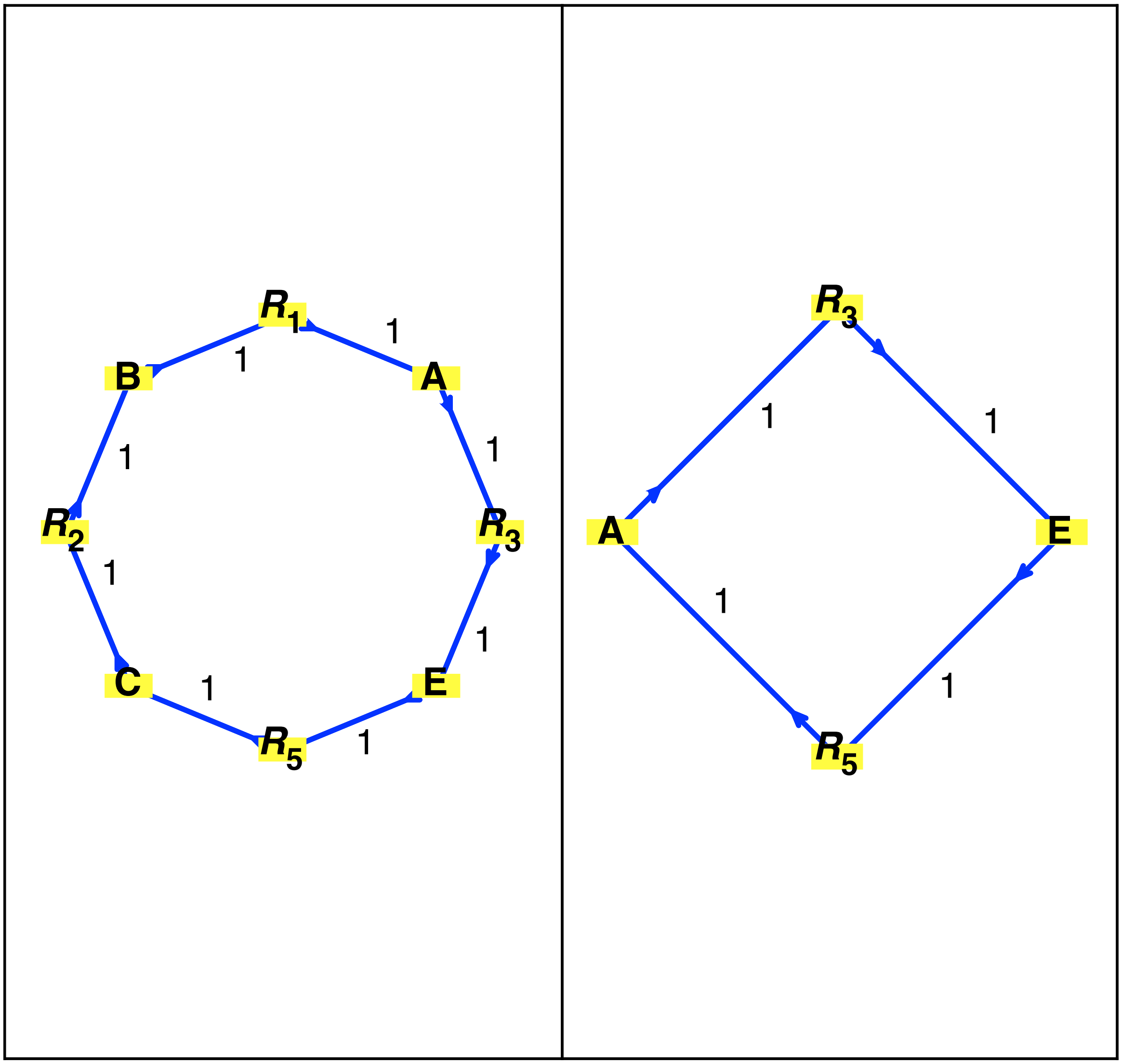
Meet both (?). NB: B is same as E, A is trimer, B & E are dimers of C & D.

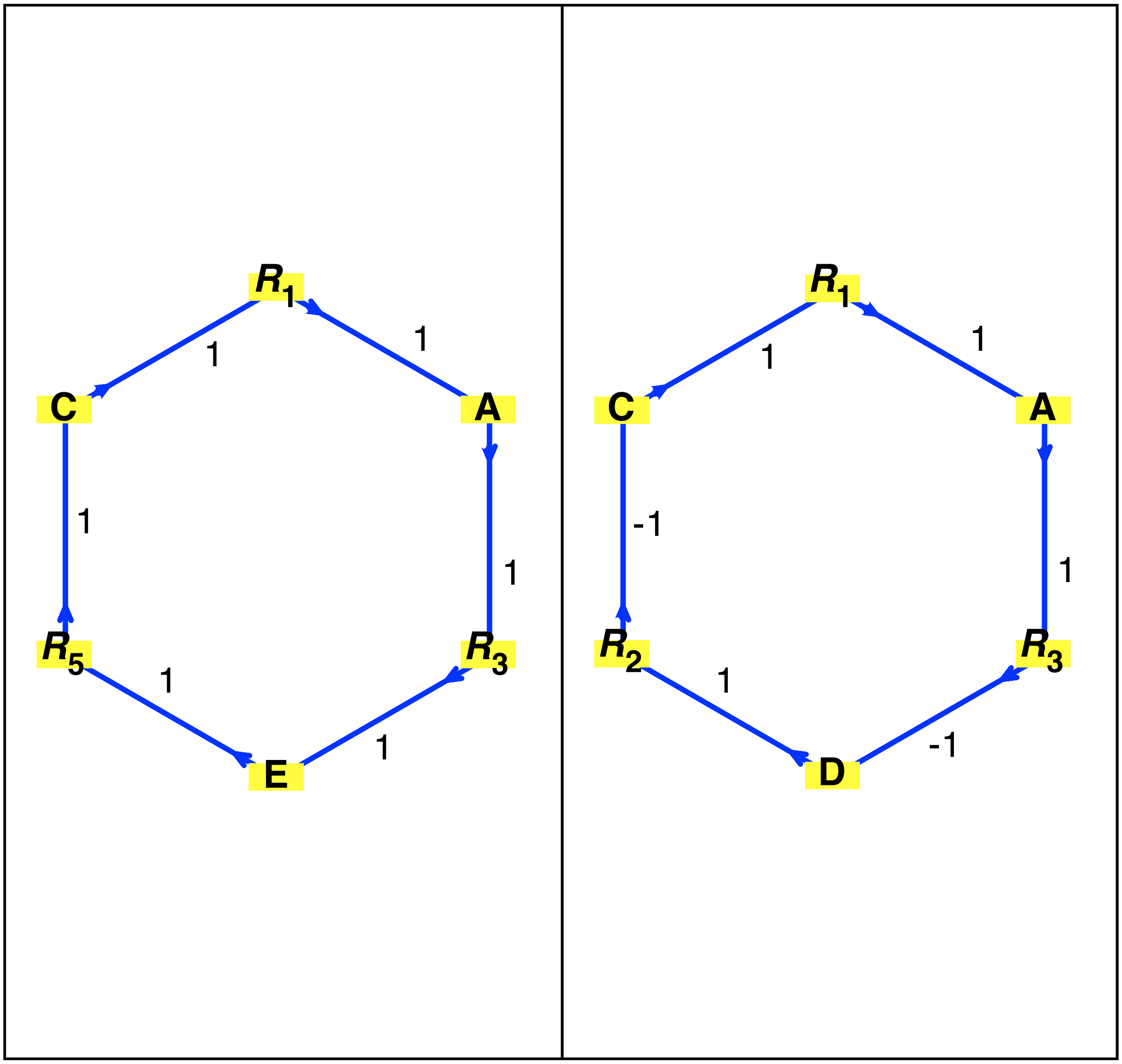
Network 3015 (meet neither, maybe not realistic) three competing reactions

$B + C \rightarrow A$
$C + \mathrm{D} \rightarrow B$
$A + \mathrm{D} \rightarrow E$
$B \rightarrow C + \mathrm{D}$
$E \rightarrow A + C$

> $A := \mathit{ImportMatrix}(\mathit{cat}(\mathit{uniquefolder}, \text{"/injectiveEx3\_3015.csv"})); Z := \mathit{findZ}(A):$
$\mathit{selected} := \mathit{findloops}(A, Z) : \mathit{drawloops}(\mathit{selected}, \mathit{speciesord})$

$$A := \begin{bmatrix} 1 & 0 & -1 & 0 & 1 \\ -1 & 1 & 0 & -1 & 0 \\ -1 & -1 & 0 & 1 & 1 \\ 0 & -1 & -1 & 1 & 0 \\ 0 & 0 & 1 & 0 & -1 \end{bmatrix}$$





>

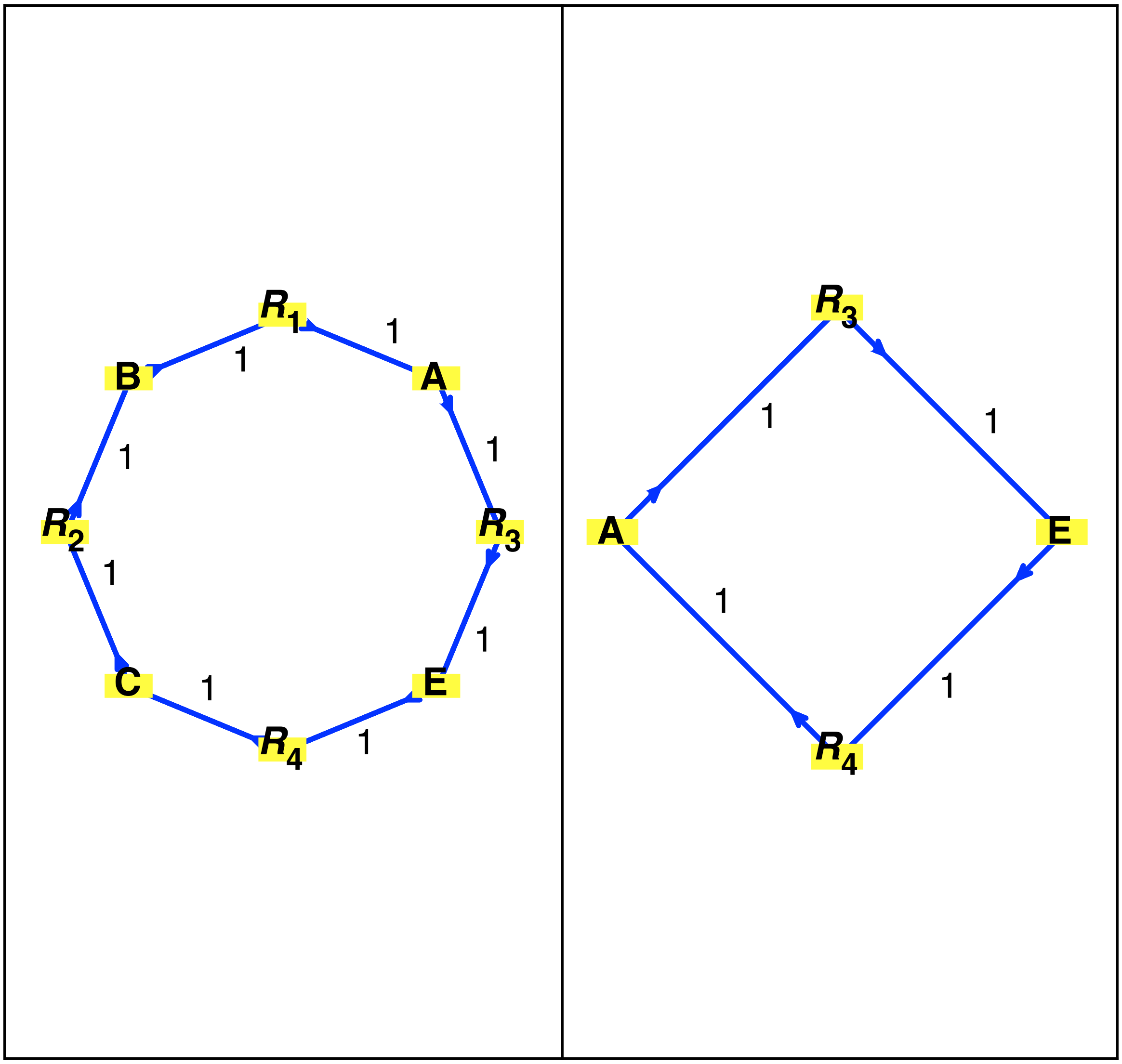
Meet both (?). NB: E is tetramer, A is trimer, B is dimer of C & D.

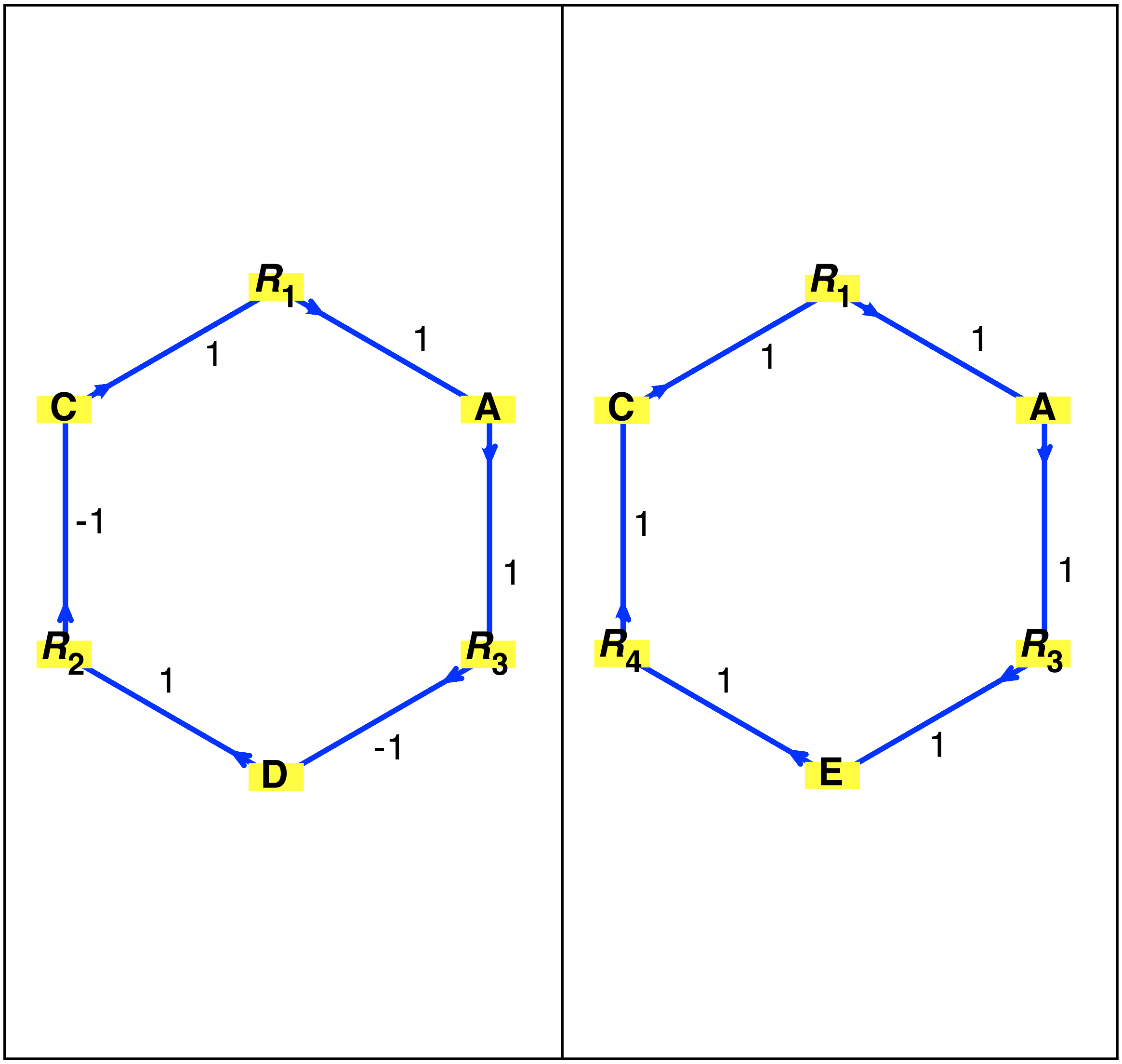
Network 3017 (meet neither, maybe not realistic) three competing reactions

$B + C \to A$
$C + \mathrm{D} \to B$
$A + \mathrm{D} \to E$
$E \to A + C$
$E \to A + \mathrm{D}$

> $A := ImportMatrix(cat(uniquefolder, \text{"/injectiveEx3\_3017.csv"})); Z := findZ(A) :$
$selected := findloops(A, Z) : drawloops(selected, speciesord)$

$$A := \begin{bmatrix} 1 & 0 & -1 & 1 & 1 \\ -1 & 1 & 0 & 0 & 0 \\ -1 & -1 & 0 & 1 & 0 \\ 0 & -1 & -1 & 0 & 1 \\ 0 & 0 & 1 & -1 & -1 \end{bmatrix}$$





>

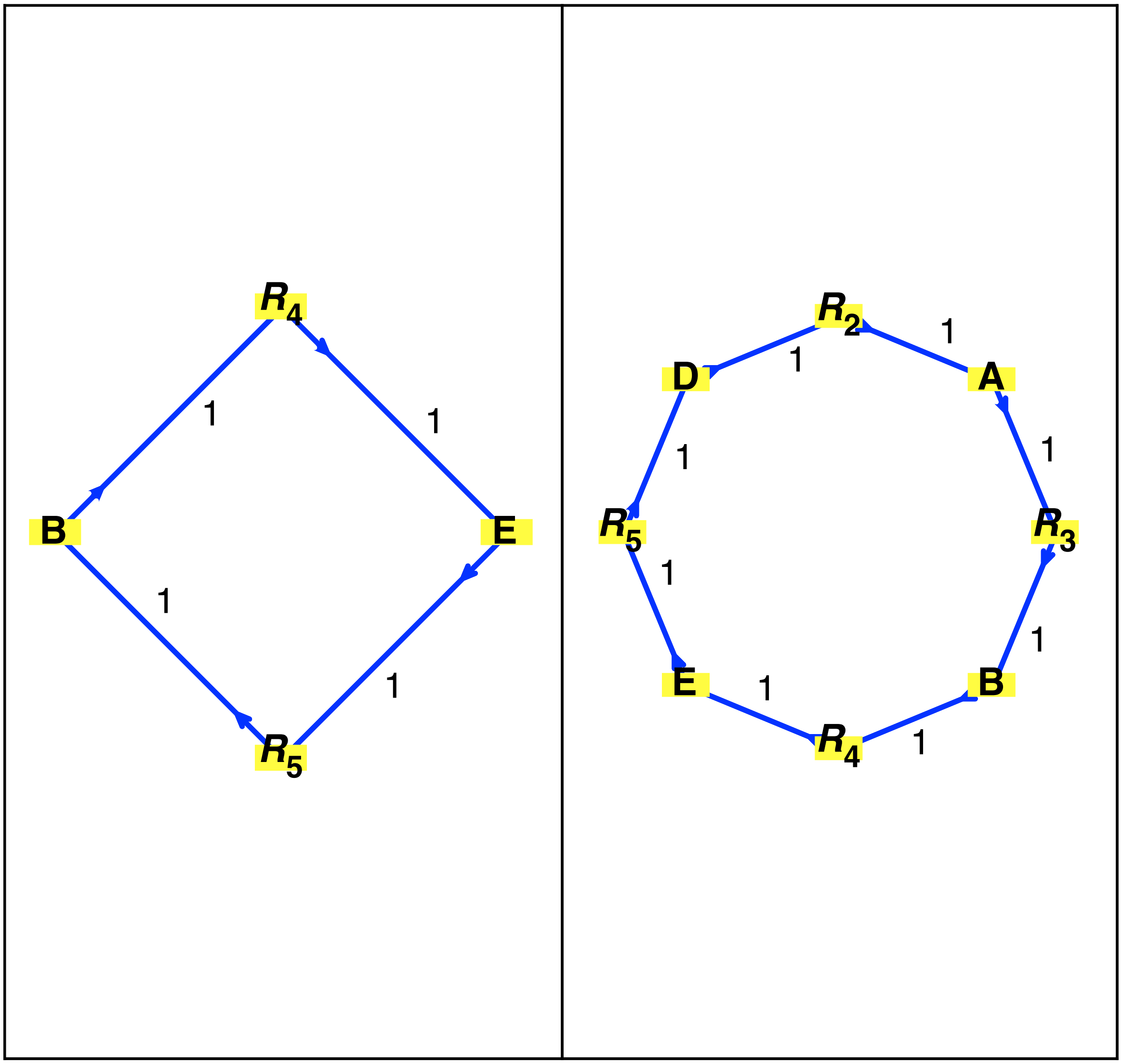
Meet both (?). NB: E is tetramer, A is trimer, B is dimer of C & D. A catalyze D to C

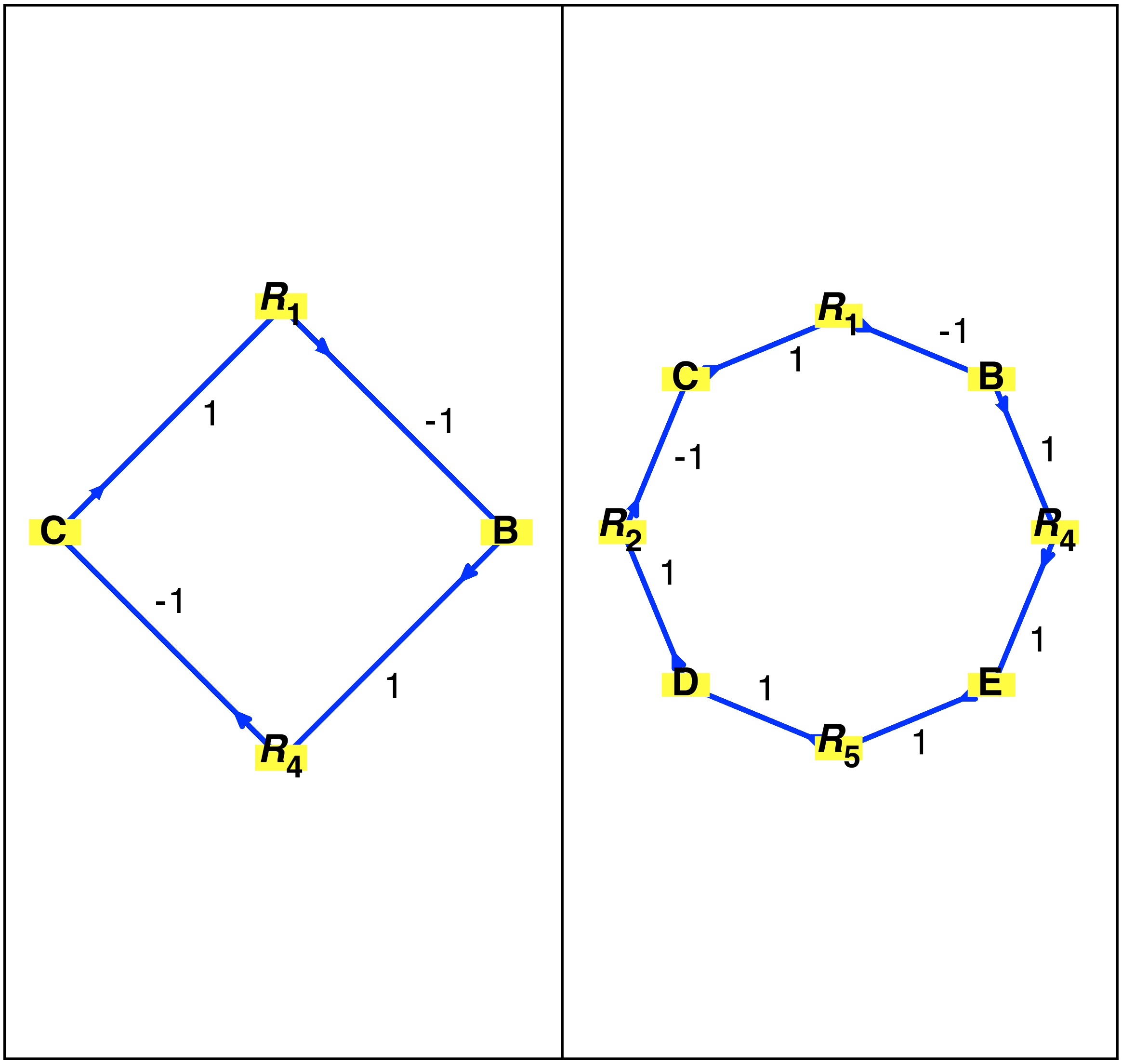
Network 3110 (meet neither, not realistic) three competing reactions

$B + C \rightarrow A$
$C + \mathrm{D} \rightarrow A$
$A \rightarrow B + C$
$B + C \rightarrow E$
$E \rightarrow B + \mathrm{D}$

> $A := ImportMatrix(cat(uniquefolder, \text{"/injectiveEx3\_3110.csv"})); Z := findZ(A) :$
$selected := findloops(A, Z) : drawloops(selected, speciesord)$

$$A := \begin{bmatrix} 1 & 1 & -1 & 0 & 0 \\ -1 & 0 & 1 & -1 & 1 \\ -1 & -1 & 1 & -1 & 0 \\ 0 & -1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & -1 \end{bmatrix}$$





>

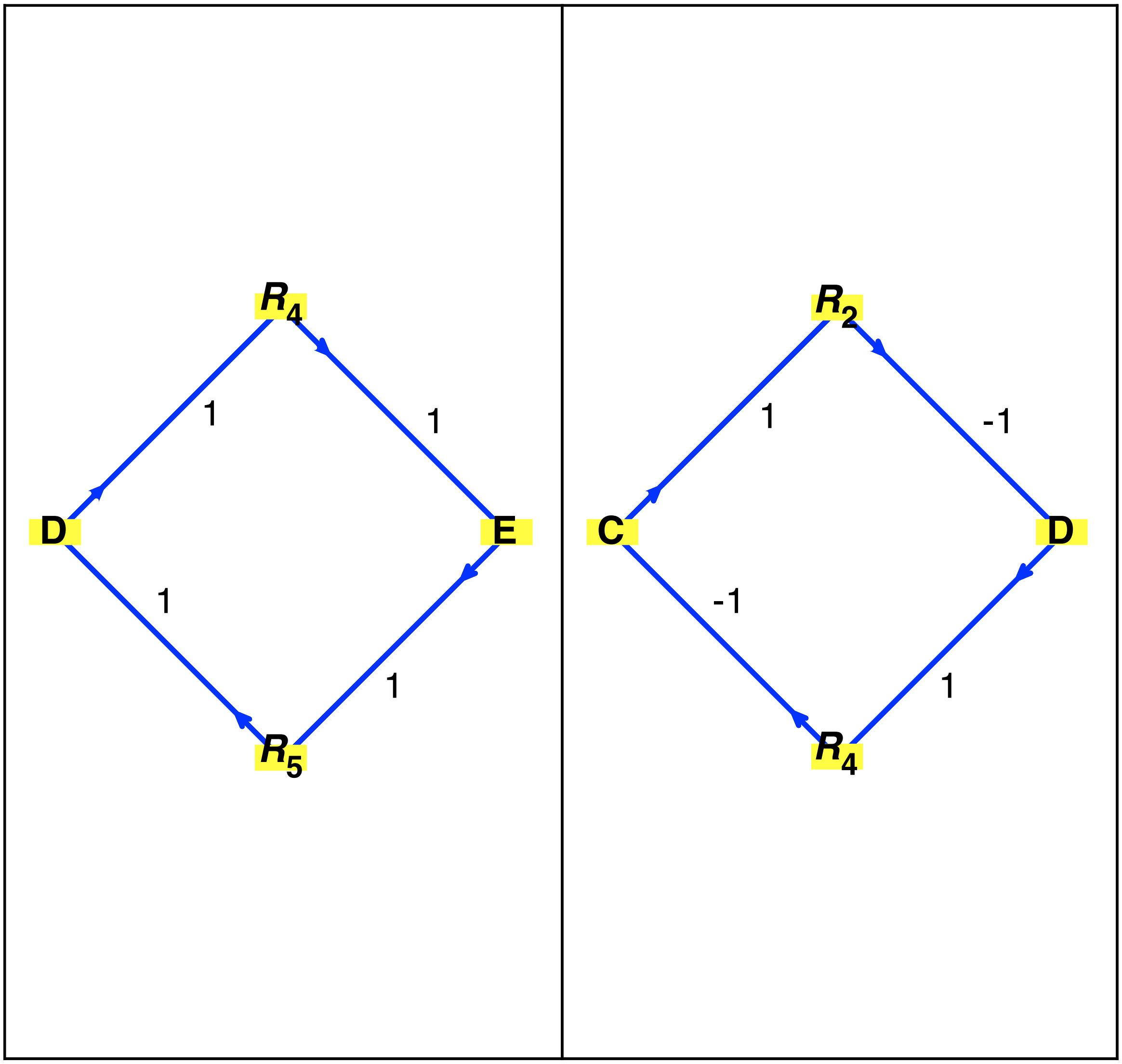
Meet both (?). NB: D is same as B. C, B, D are three states. A & E are dimer of B, C & D. C catalyze D to B, B catalyze C to D.

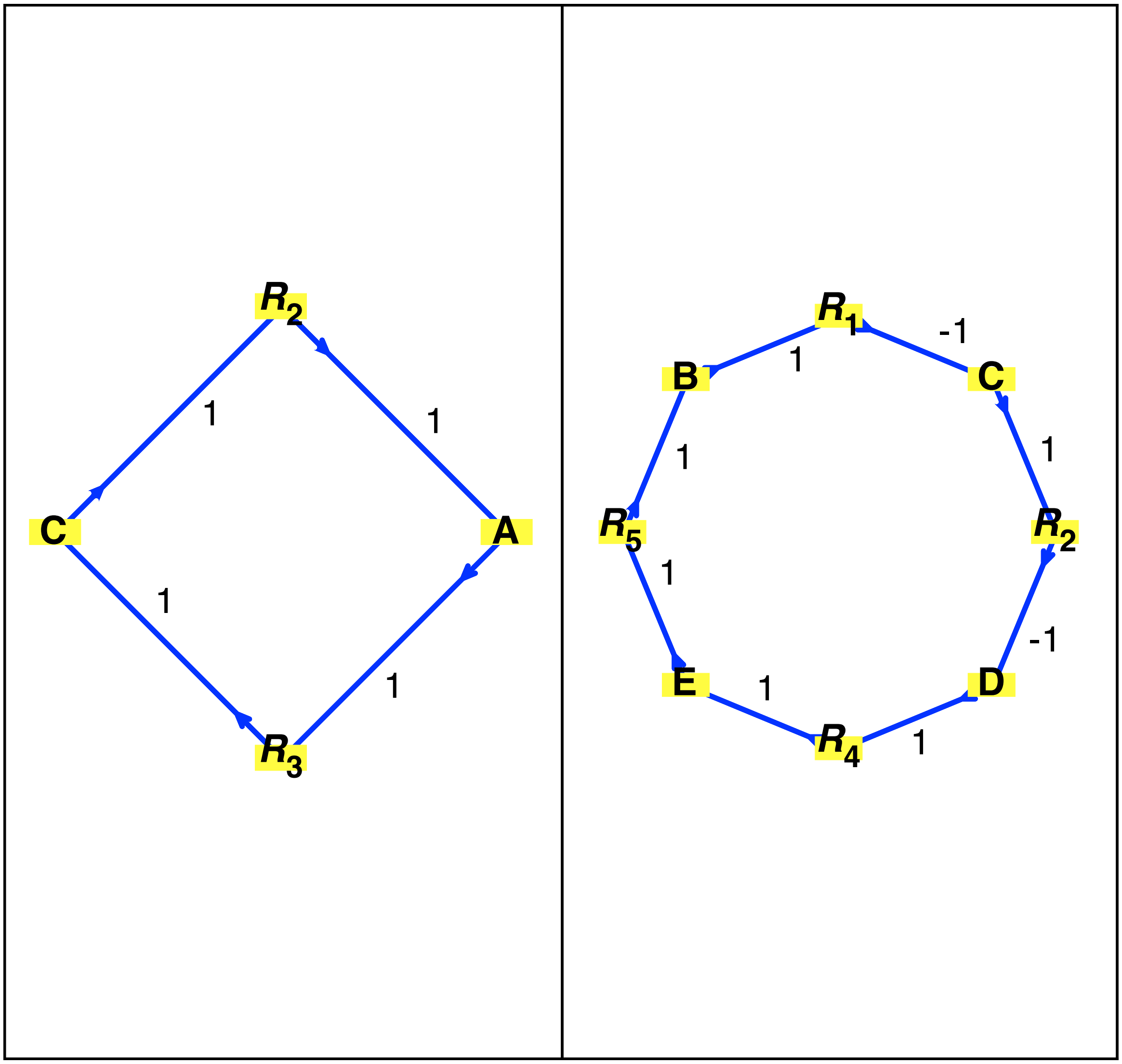
Network 3118 (meet neither, not realistic) three competing reactions

$B + C \rightarrow A$
$C + \mathrm{D} \rightarrow A$
$A \rightarrow B + C$
$C + \mathrm{D} \rightarrow E$
$E \rightarrow B + \mathrm{D}$

> $A := ImportMatrix(cat(uniquefolder, \text{"/injectiveEx3\_3118.csv"}));\ Z := findZ(A):$
> $selected := findloops(A, Z) : drawloops(selected, speciesord)$

$$A := \begin{bmatrix} 1 & 1 & -1 & 0 & 0 \\ -1 & 0 & 1 & 0 & 1 \\ -1 & -1 & 1 & -1 & 0 \\ 0 & -1 & 0 & -1 & 1 \\ 0 & 0 & 0 & 1 & -1 \end{bmatrix}$$





>

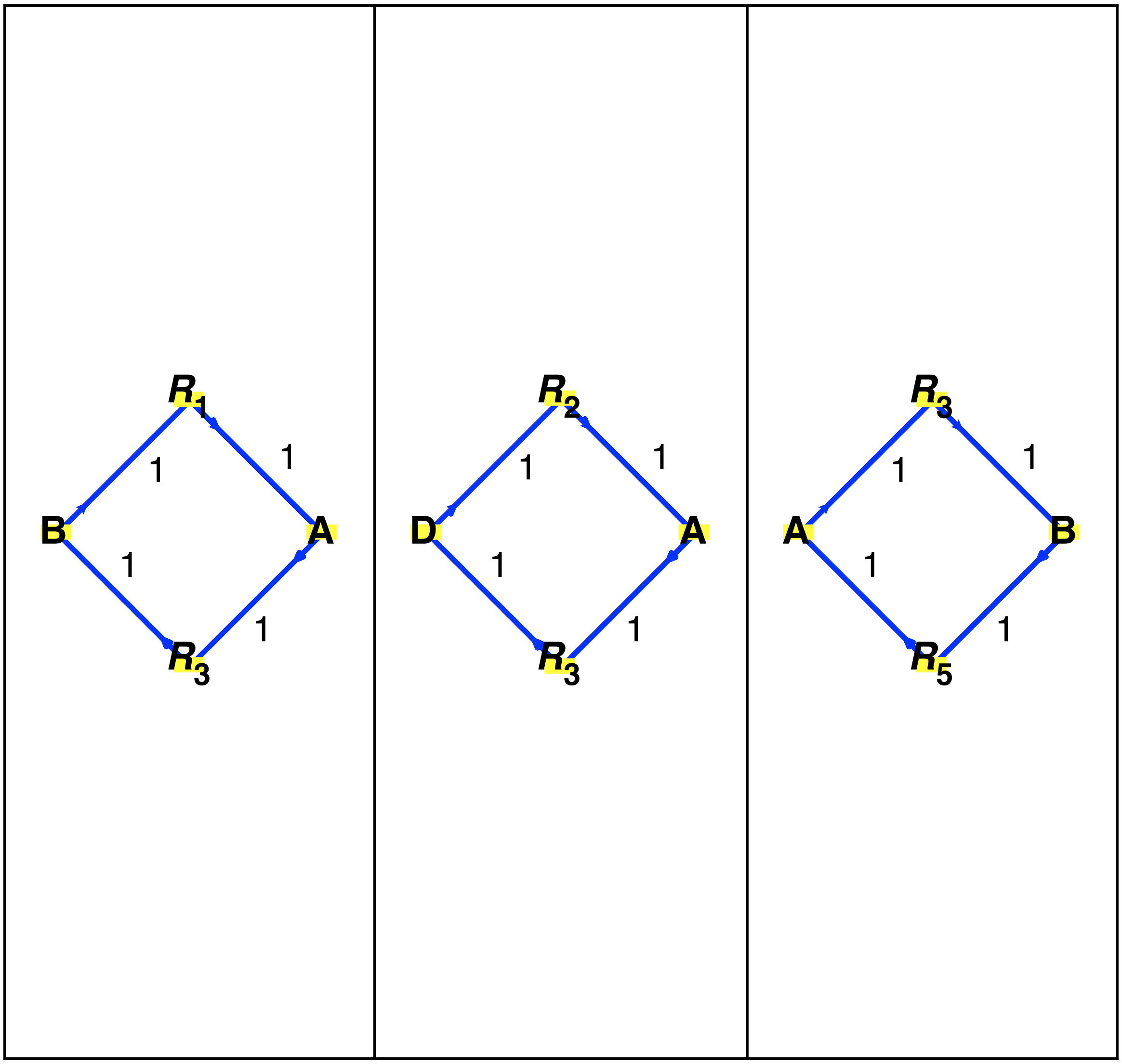
Meet both (?). NB: A is same as E. B is same as D. C, B, D are three states. A & E are dimer of B, C & D. C catalyze D to B, D catalyze C to B.

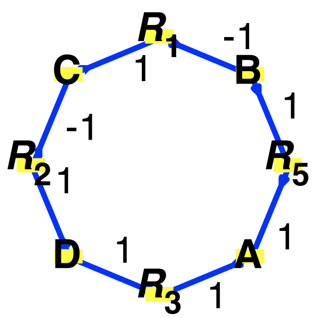
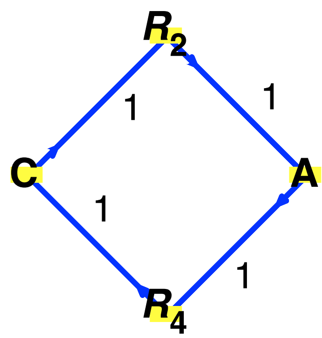
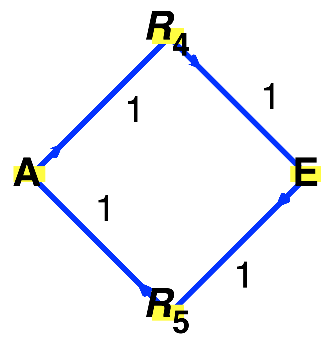
Network 3123 (meet neither, not realistic) three competing reactions

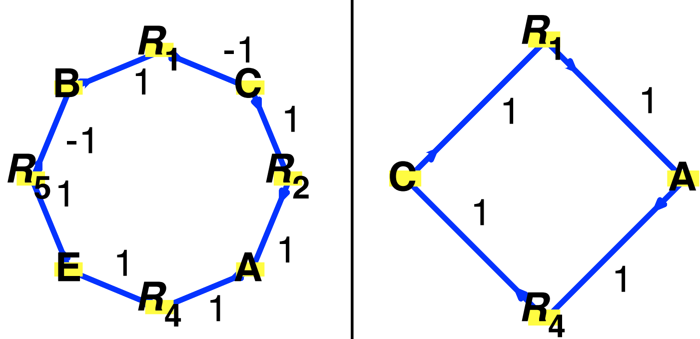
$B + C \rightarrow A$
$C + \mathrm{D} \rightarrow A$
$A \rightarrow B + \mathrm{D}$
$A \rightarrow C + E$
$E + B \rightarrow A$

> $A := ImportMatrix(cat(uniquefolder, \text{"/injectiveEx3\_3123.csv"})); Z := findZ(A) :$
$selected := findloops(A, Z) : drawloops(selected, speciesord)$

$$A := \begin{bmatrix} 1 & 1 & -1 & -1 & 1 \\ -1 & 0 & 1 & 0 & -1 \\ -1 & -1 & 0 & 1 & 0 \\ 0 & -1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & -1 \end{bmatrix}$$



 R1 C B R2 R5 D A R3 -1 1 1 -1 1 1 1 1	 R2 C A R4 1 1 1 1	 R4 A E R5 1 1 1 1



>

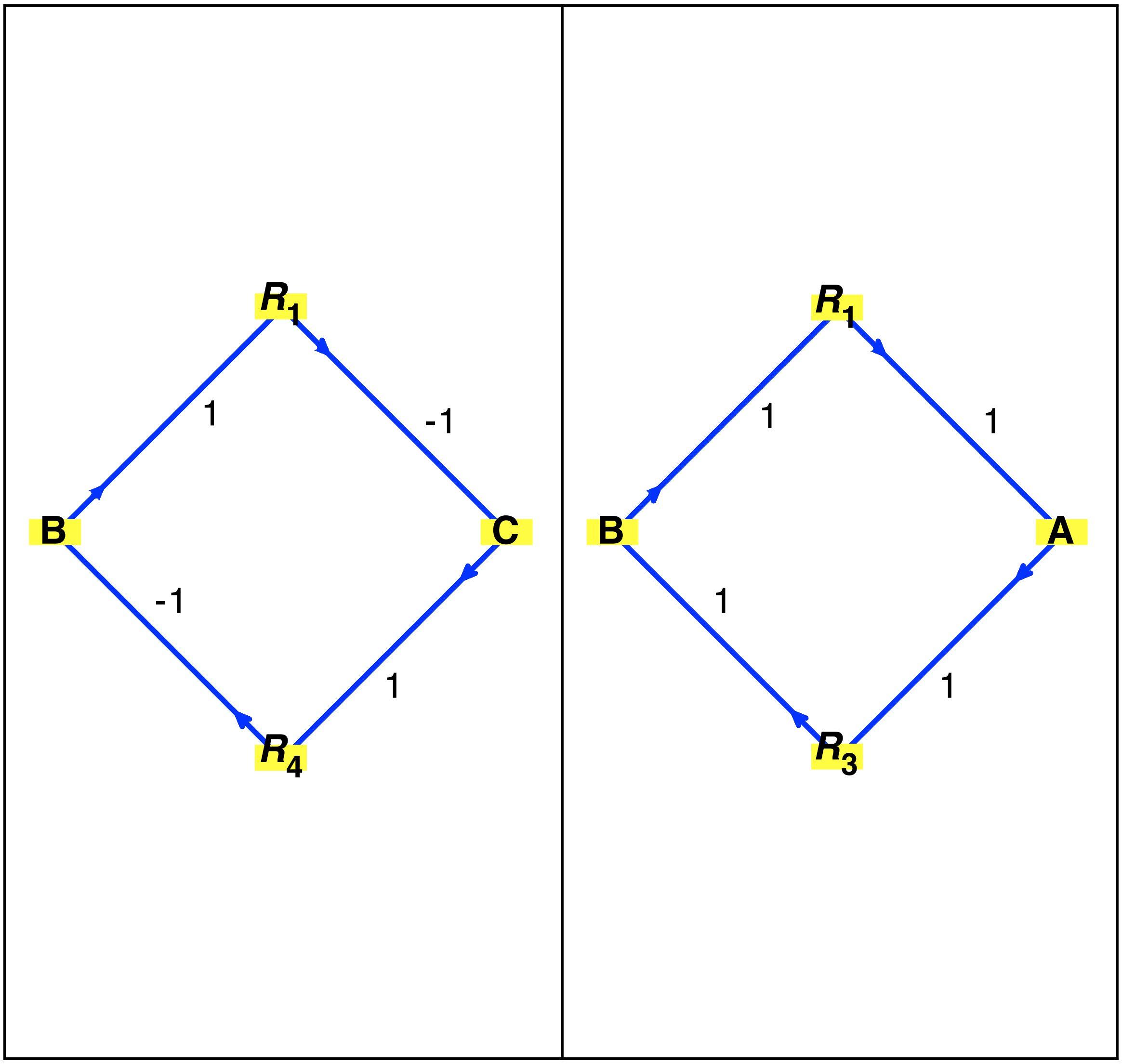
Meet both (?). NB: A dimer of B, C, D & E.

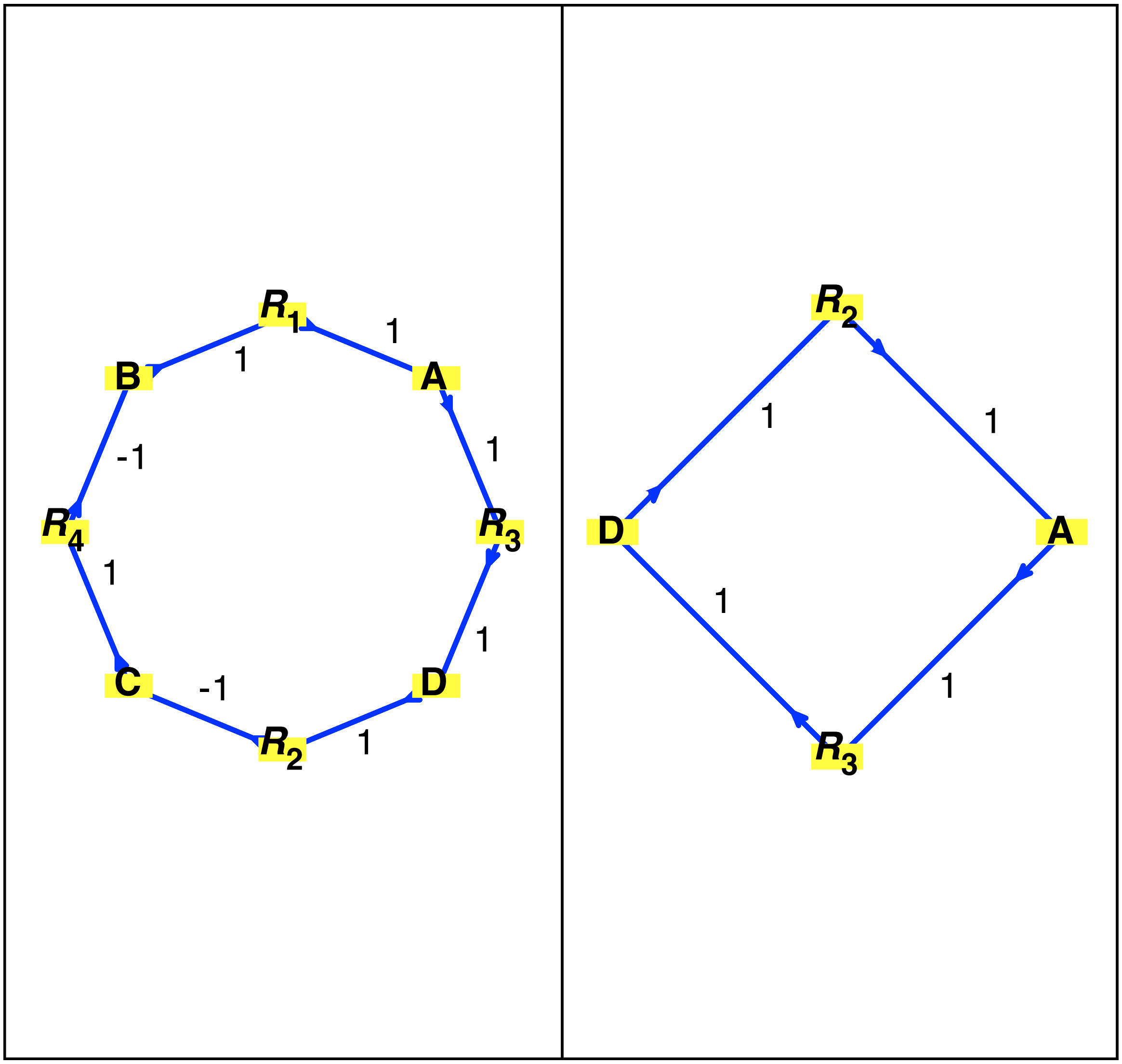
Network 3128 (meet neither, not realistic) three competing reactions

$B + C \rightarrow A$
$C + \mathrm{D} \rightarrow A$
$A \rightarrow B + \mathrm{D}$
$B + C \rightarrow E$
$E \rightarrow B + C$

> $A := ImportMatrix(cat(uniquefolder, \text{"/injectiveEx3\_3128.csv"})); Z := findZ(A) :$
$selected := findloops(A, Z) : drawloops(selected, speciesord)$

$$A := \begin{bmatrix} 1 & 1 & -1 & 0 & 0 \\ -1 & 0 & 1 & -1 & 1 \\ -1 & -1 & 0 & -1 & 1 \\ 0 & -1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & -1 \end{bmatrix}$$





>

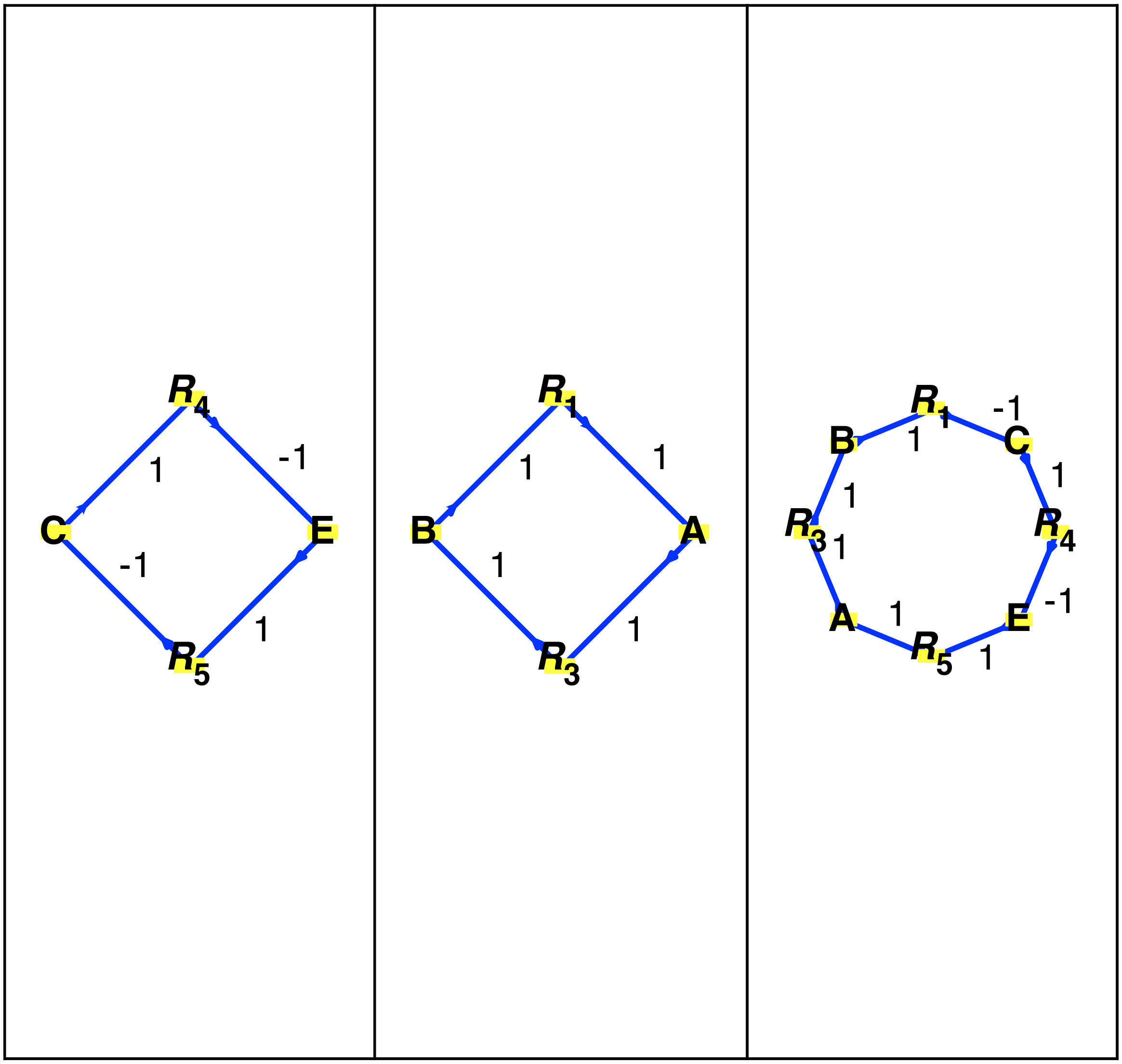
Meet both (?). NB: B is same as D, A is same as E.

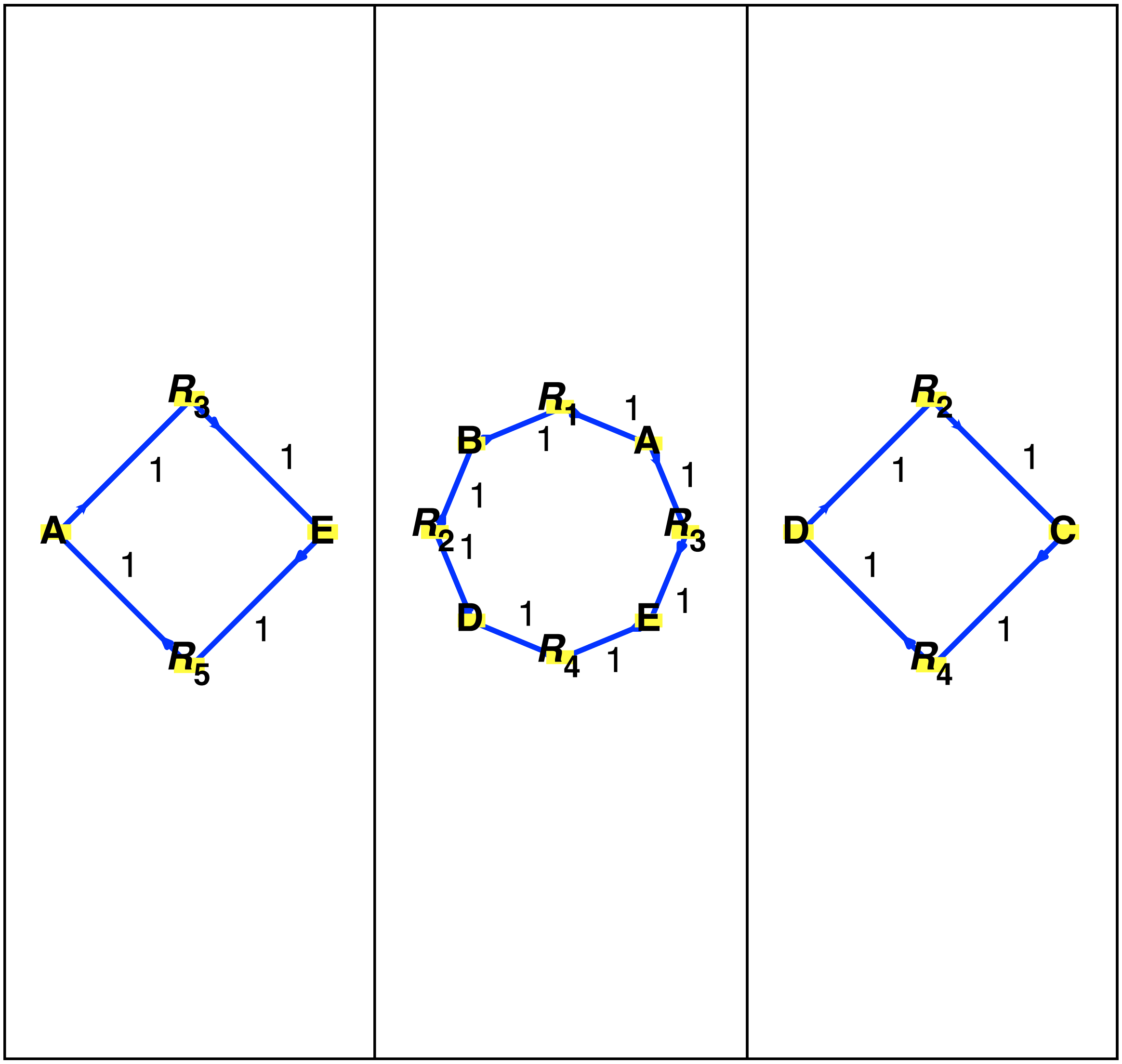
Network 3555 (meet neither, not realistic) three competing reactions

$B + C \rightarrow A$
$\mathrm{D} \rightarrow B + C$
$A \rightarrow B + E$
$C + E \rightarrow \mathrm{D}$
$C + E \rightarrow A$

> $A := ImportMatrix(cat(uniquefolder, \text{"/injectiveEx3\_3555.csv"})); Z := findZ(A) : selected := findloops(A, Z) : drawloops(selected, speciesord)$

$$A := \begin{bmatrix} 1 & 0 & -1 & 0 & 1 \\ -1 & 1 & 1 & 0 & 0 \\ -1 & 1 & 0 & -1 & -1 \\ 0 & -1 & 0 & 1 & 0 \\ 0 & 0 & 1 & -1 & -1 \end{bmatrix}$$





>

Meet both (?). NB: B is same as E, A is same as D.