Bond Graphs practice

A graphical language for the analysis of multiphysical systems

$\longrightarrow$

Pierre Haessig, CentraleSupélec (campus of Rennes)
SG6: Dec. 2021 – Jan. 2022

Slide deck 3: causality

Course outline

- Bond graph objectives
- The bond graph language

  - Bonds and power variables: the physical analogy

  - Elements

- Practice: reading & creating bond graphs
- Causality and derivation of mathematical models

  - **Principles**

  - Practice

Computational causality & derivation of mathematical models
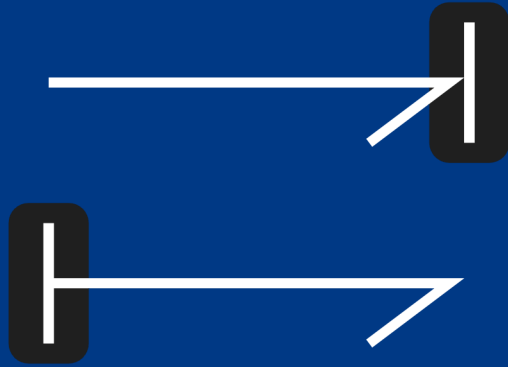
Causally completed bonds

Reminder: bonds express acausal physical links between components
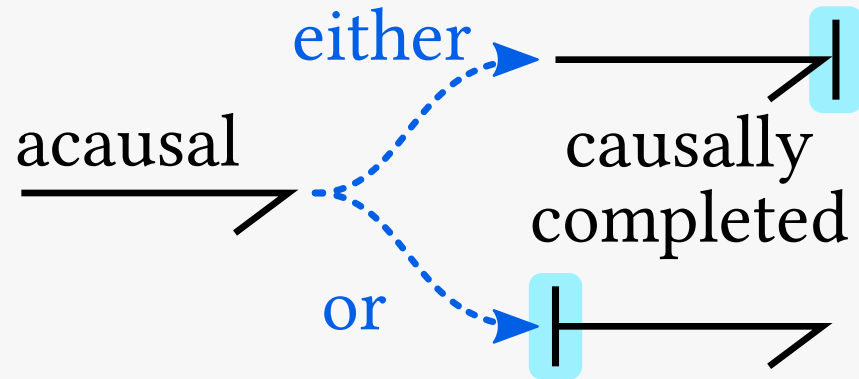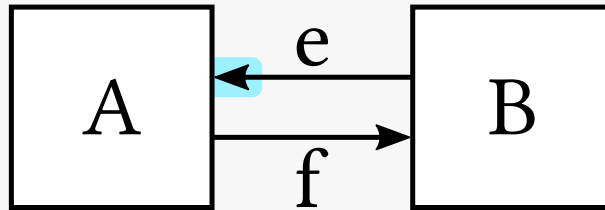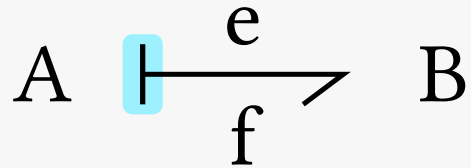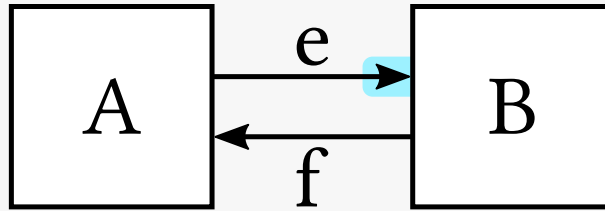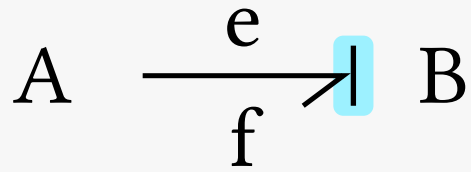

Optionnaly, bonds can be completed with **"causality stroke/arrow"** which indicate the direction of the computation flow.

Remark: this *computational* causality doesn't express a *physical* cause $\rightarrow$ consequence relationship

Meaning and significance of causality in BGs

BG to block diagrams fragments

Mnemonic: the causality arrow is the direction of the *effort signal arrow*
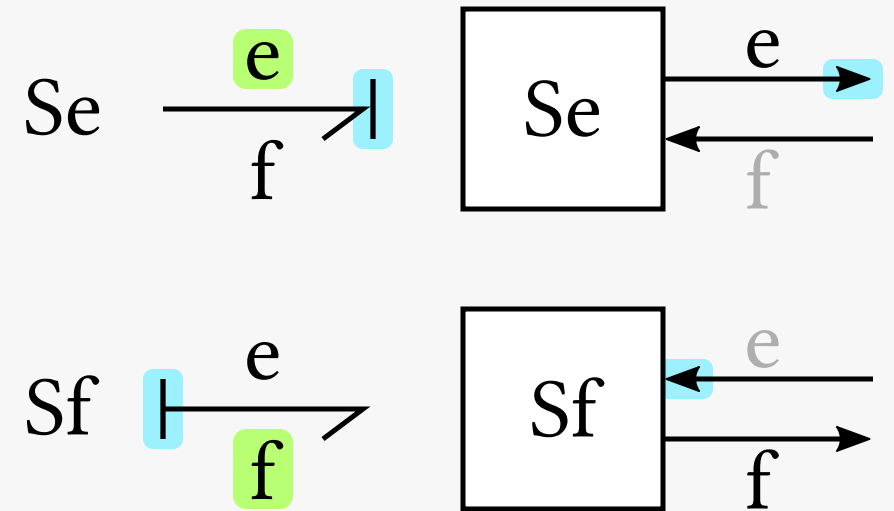
To be continued…

Rules for each class of BG components
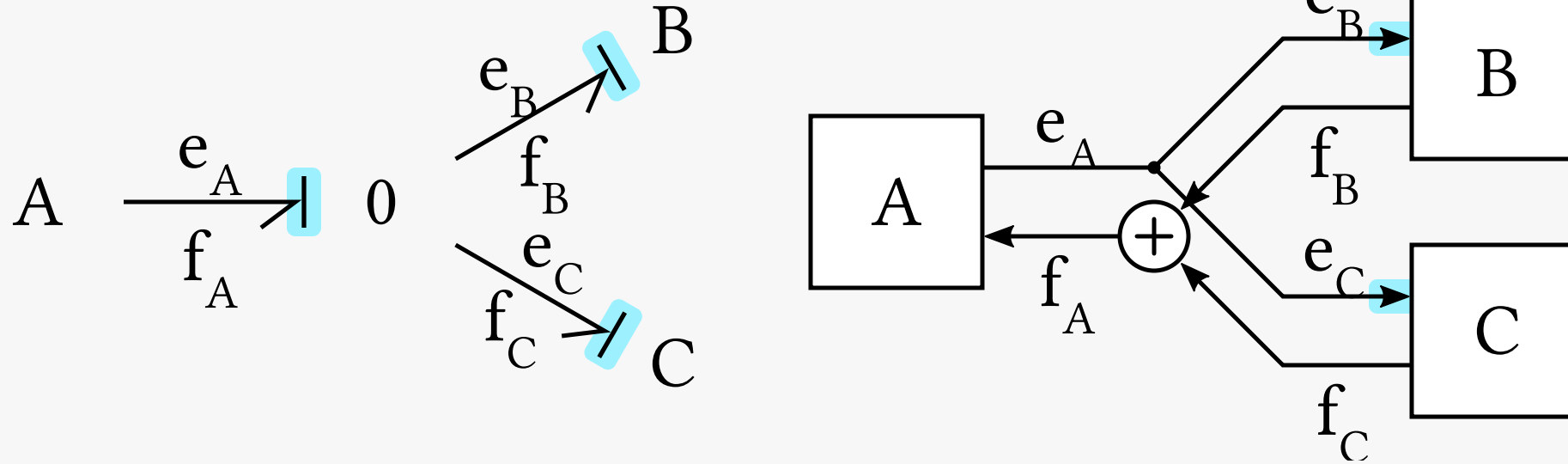
- sources

- junctions

- energy stores & dissipators

Causality for Sources

For sources, causality orientation is **compulsory**:

- Se imposes the effort
  $\rightarrow$ outgoing effort
- Sf imposes the flow
  $\rightarrow$ outgoing flow

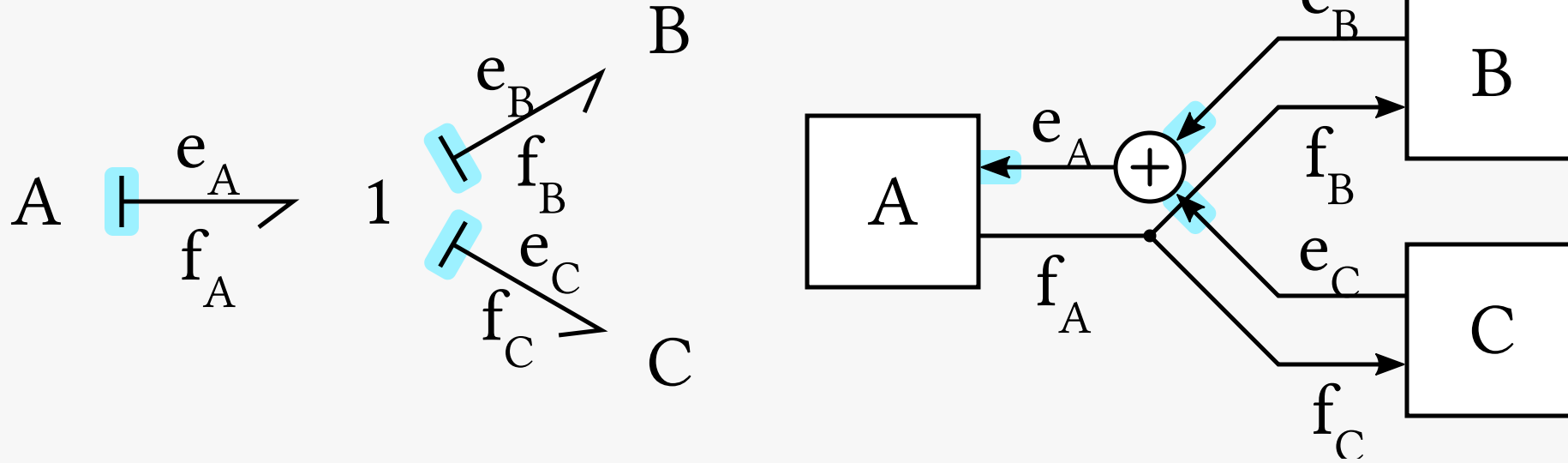# Causality for junctions: 0 junction

Compulsory rule

For 0 junction (share effort): *"One and only one incoming effort"*

Remark: causality arrows unrelated to bond orientations
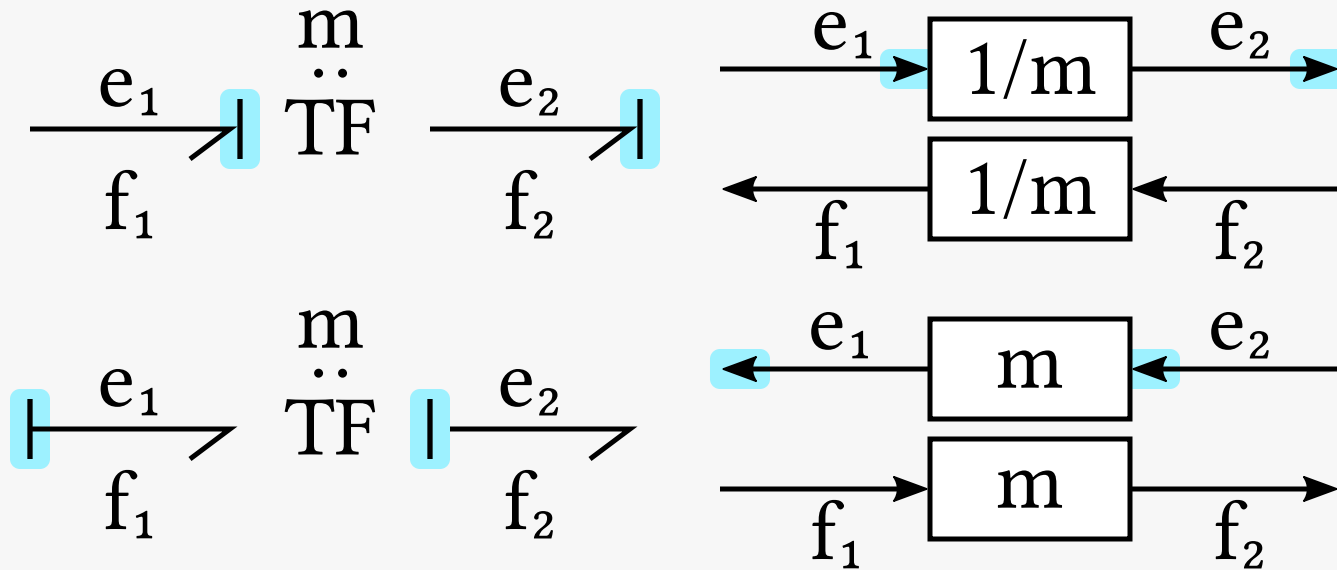
Causality for junctions: 1 junction

Compulsory rule

For 1 junction (share flow): *"One and only one incoming flow*

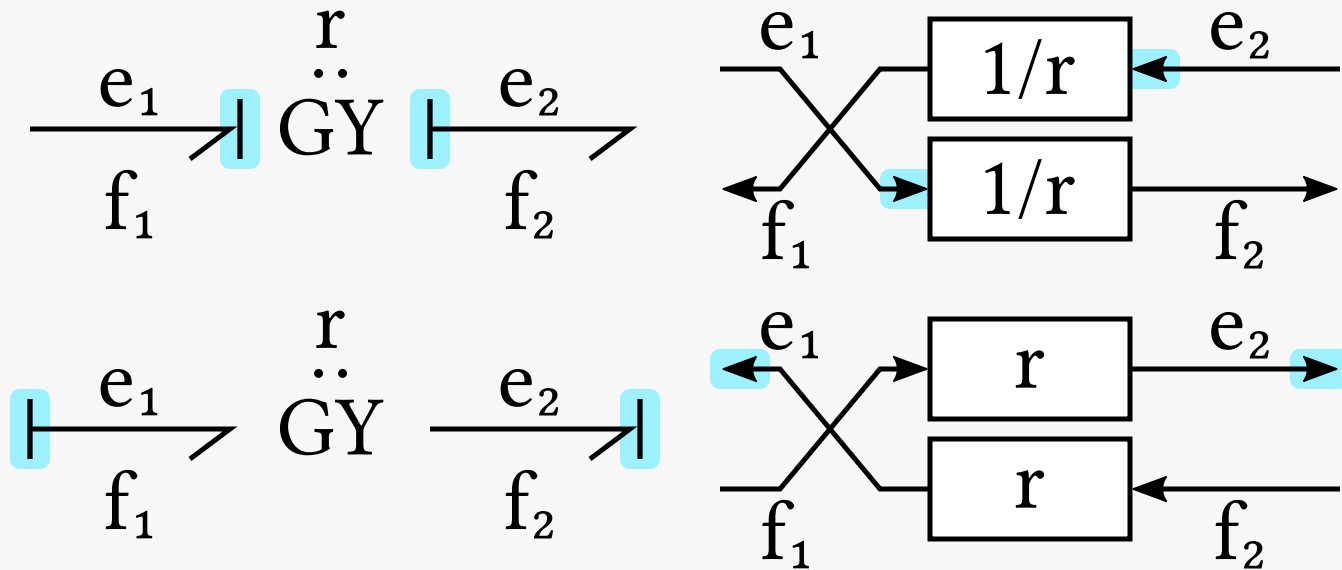Remark: causality arrows unrelated to bond orientations

Causality for junctions: TF

[Compulsory] Transformers **preserve** the direction of the e&f signals

- one incoming effort
- one incoming flow

Causality for junctions: GY

[Compulsory] Gyrators **reverse** the direction of the e&f signals

- either two incoming efforts
- or two incoming flows

Causality for Energy stores

C and I energy stores can accept the two possible causalities:

- **Integral causality** is the one yielding an integrator block

- **Derivative causality** is the one yielding an derivator block

For computational easiness, integrators are prefered, so
Integral causality = **Prefered** causality

Causality for Energy stores: C

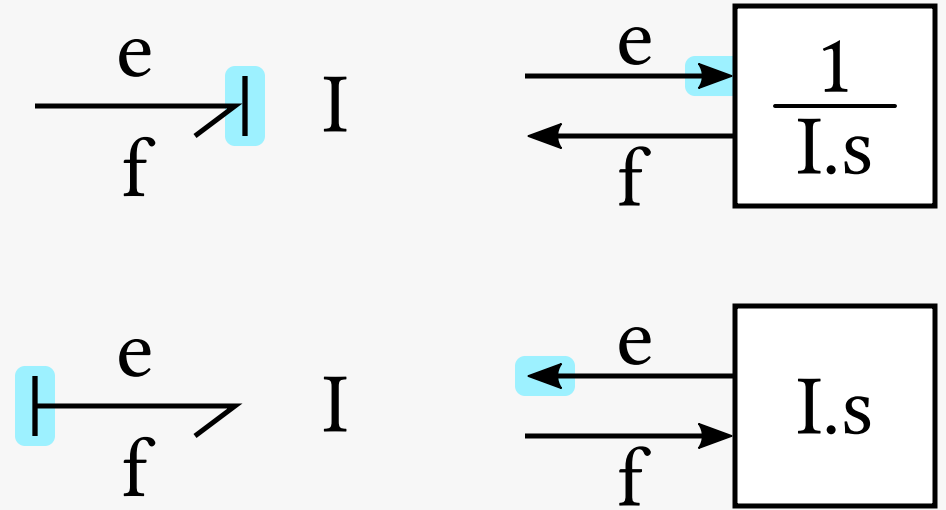Integral causality: receives a flow, imposes an effort

- Capacitor: current $\rightarrow$ voltage
- Spring: speed/position $\rightarrow$ force
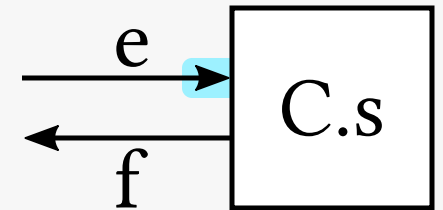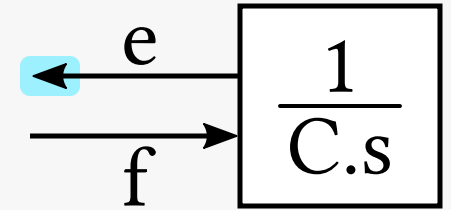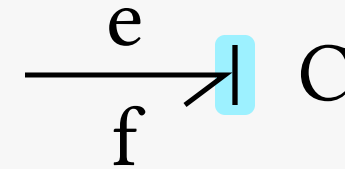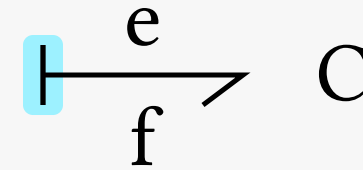
Causality for Energy stores: I

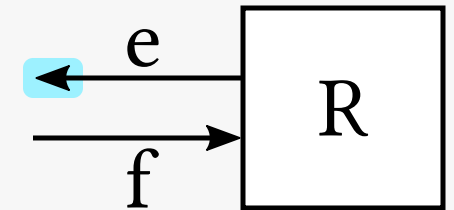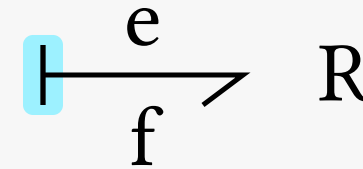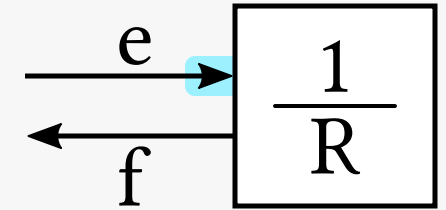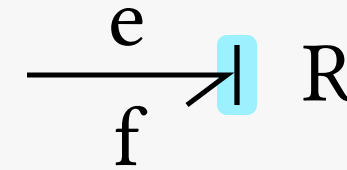Integral causality: receives a flow, imposes an effort

- Inductor: voltage $\rightarrow$ current
- Intertia: force $\rightarrow$ speed

Causality for R (dissipators)

For dissipators, all orientiations are fine.

Sometimes called "resistance" vs "conductance" causality

Sequential assignement rules

SCAP procudure:

Rule 1: assign sources

Rule 2: assig integral causality to Energy stores

Causality assignment examples

- Ex1: Rule 1 (sources+propagation) is enough
- Ex2: Rule 1+2 (prefered causality for energy stores) are enough