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Introducing Object-Oriented Modeling Using Pre-Built Components

Workshop # 231 at the 40th International System Dynamics Conference

2022-07-22 Frankfurt, Germany
Guido Wolf Reichert (BSL MANAGEMENT SUPPORT) & Jan Brugård (Wolfram MathCore)

A Quick Introduction To Object-Oriented Modeling

... and some background

P POLITICAL

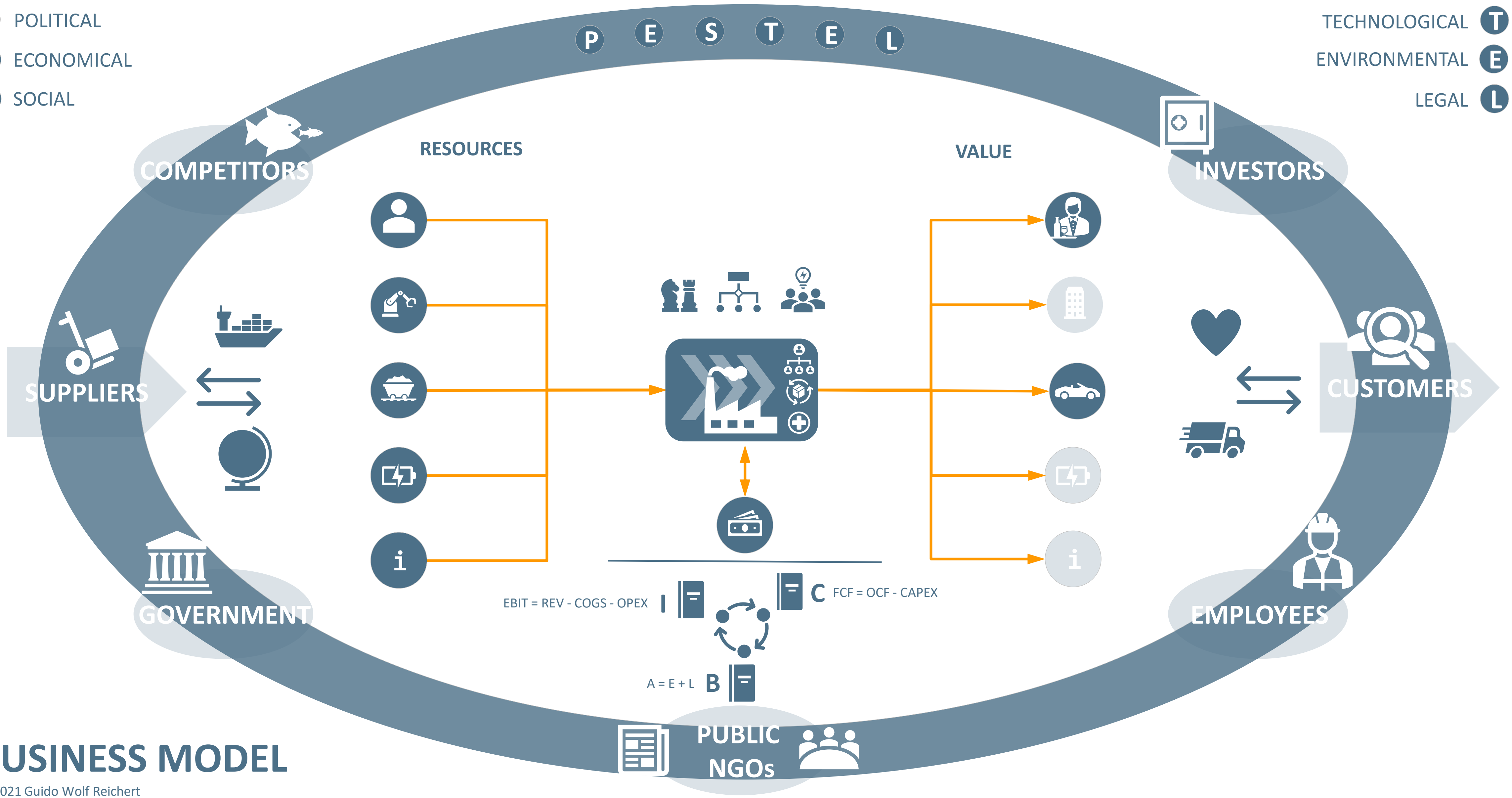
E ECONOMICAL

S SOCIAL

TECHNOLOGICAL T

ENVIRONMENTAL E

LEGAL L



BUSINESS MODEL

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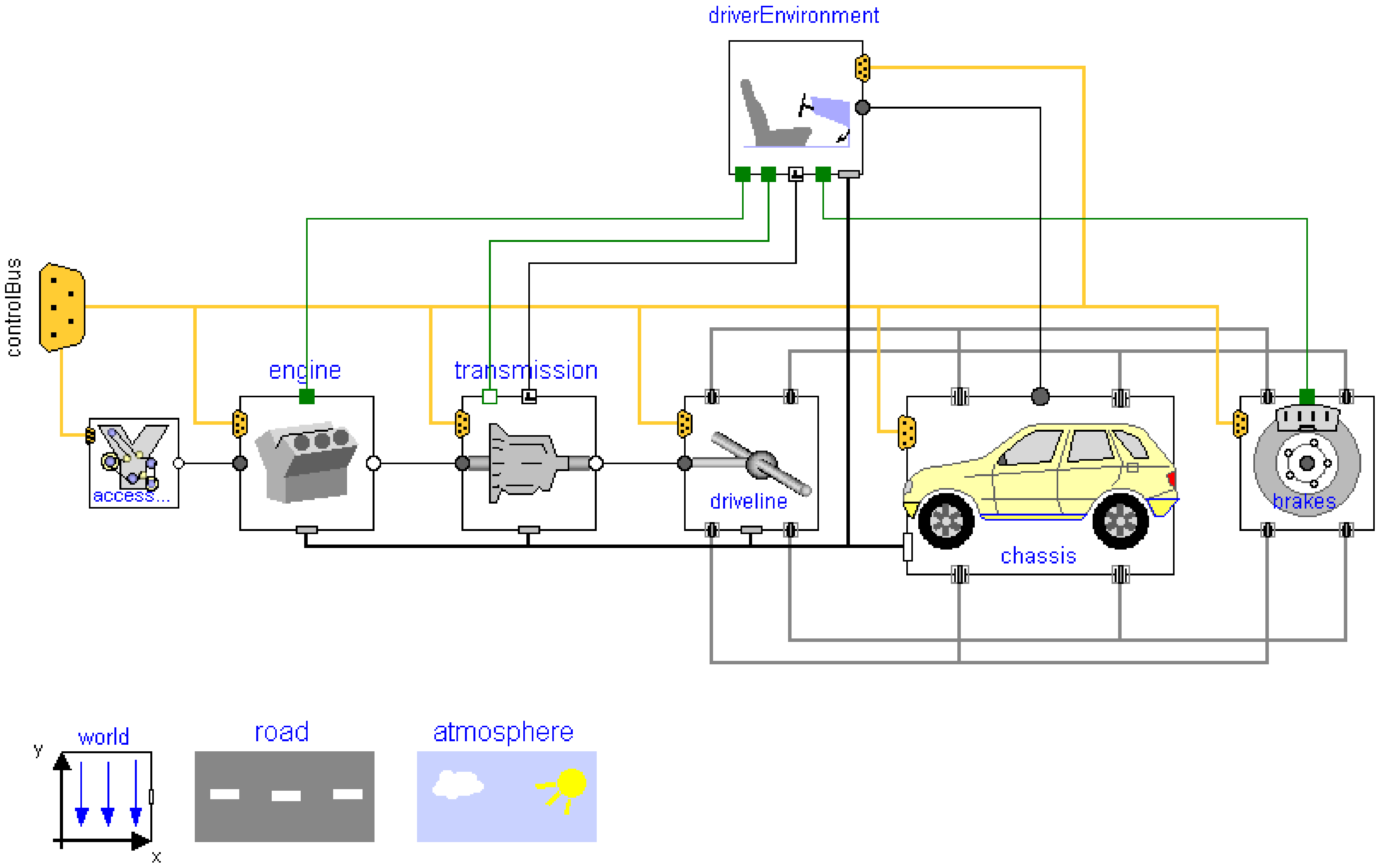

Source: Documentation of the free VehicleInterfaces Library

What we want when we model large, complex systems ...

Wishlist

- model an enterprise or organization—or at least relevant parts—in a nested, **hierarchical** fashion (“system of systems” approach)
- (re-)use **pre-built components**, i.e., ideally simply connect and parameterize subsystems with expressive icons
- components should be **self-contained including documentation** and stored separately in readable textual form to **support collaboration** and modern version control, e.g., Git
- have our final model **fit on a single page** and look (a lot) like the Business Model chart, i.e., the real system’s structure should be immediately apparent at one glance
- make models easily deployable for **model exchange and co-simulation** of different models, e.g., models may come from different sources

WOLFRAM SYSTEM MODELER
Driving insight, innovation and results

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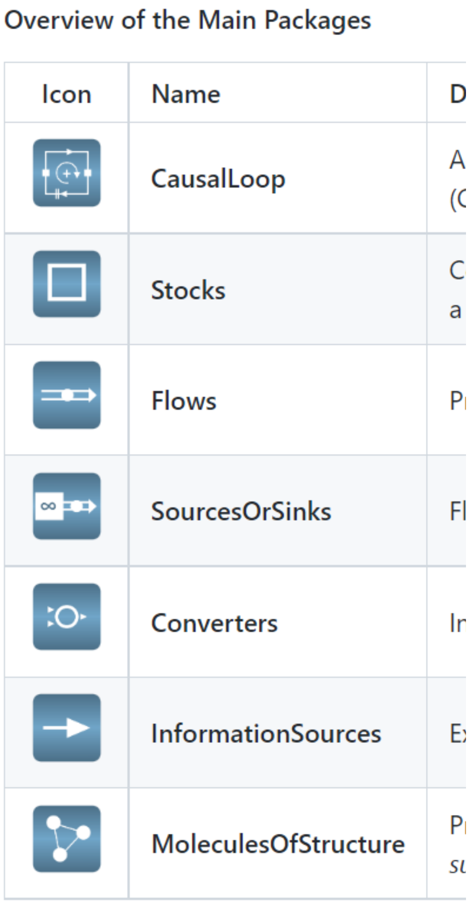
BSL

The Business Simulation Library—A quick overview

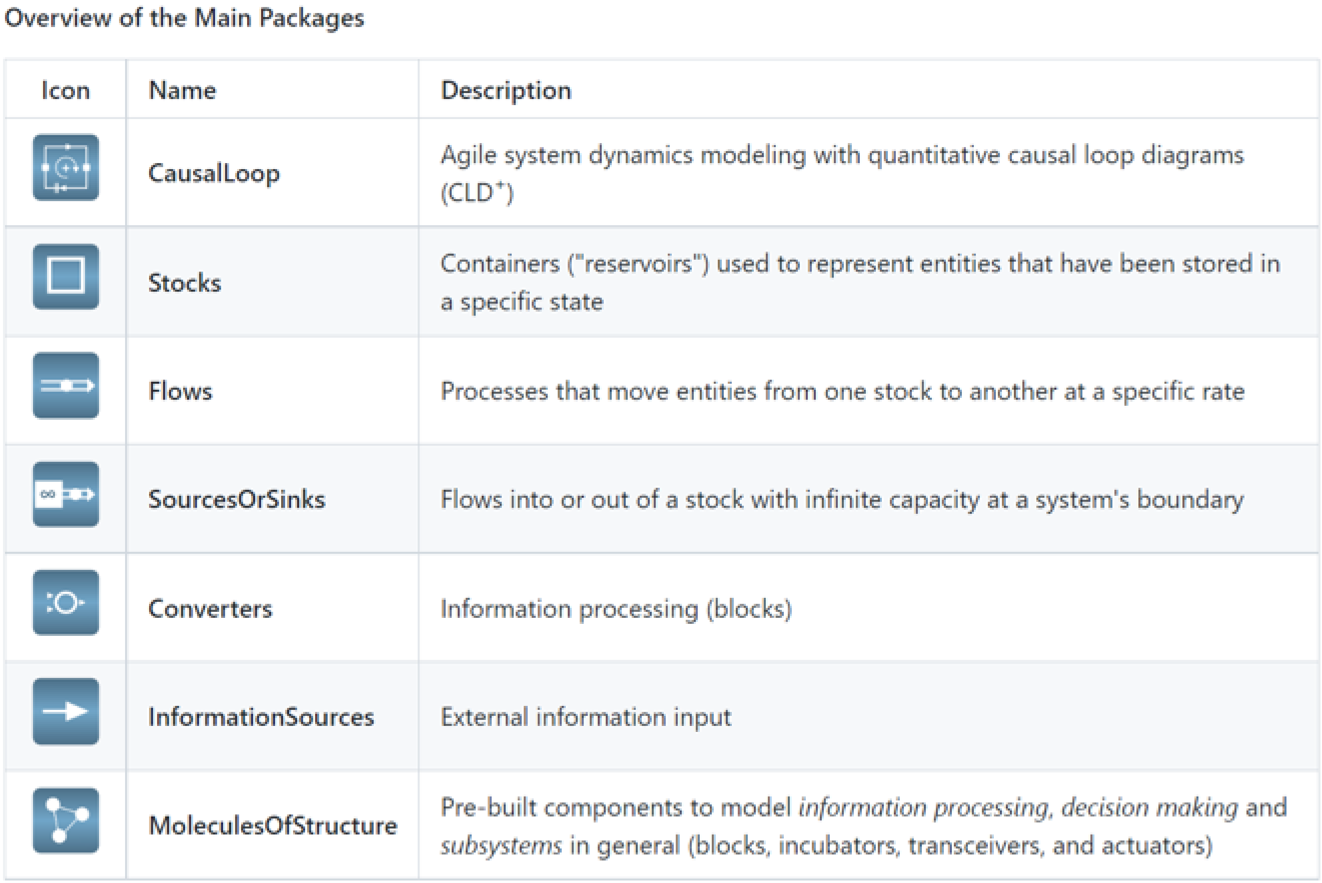
Overview



Overview of the Main Packages

Icon	Name	D
	CausalLoop	A (C
	Stocks	C a
	Flows	Pr
	SourcesOrSinks	Fl
	Converters	Ir
	InformationSources	E:
	MoleculesOfStructure	Pr *su*

Source: https://github.com/bslMS/BusinessSimulation



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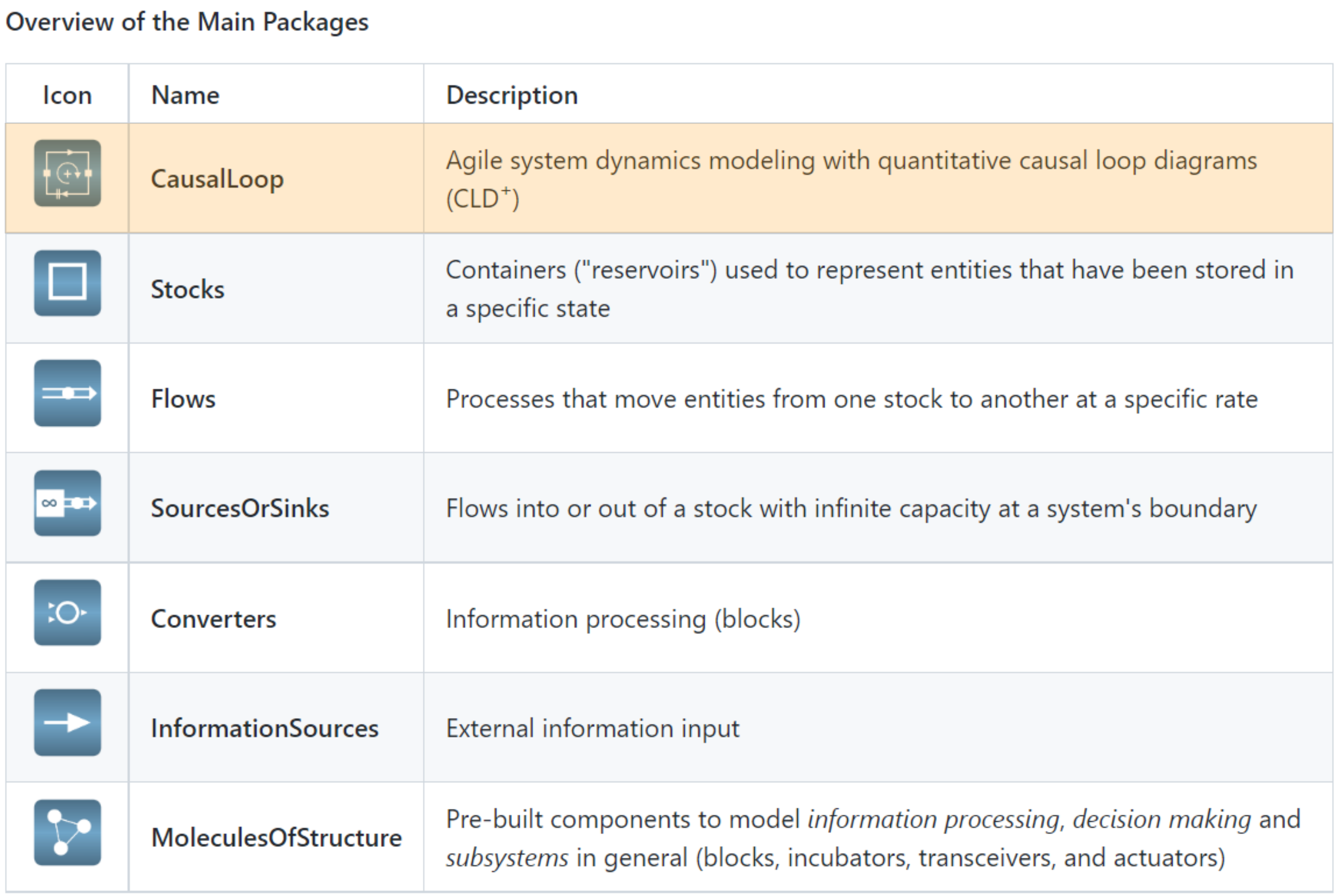
Source: https://github.com/bslMS/BusinessSimulation

Use coefficients of proportionality or elasticity and elementary processes to have causal loop diagrams spell out “*agile system dynamics*”

Overview



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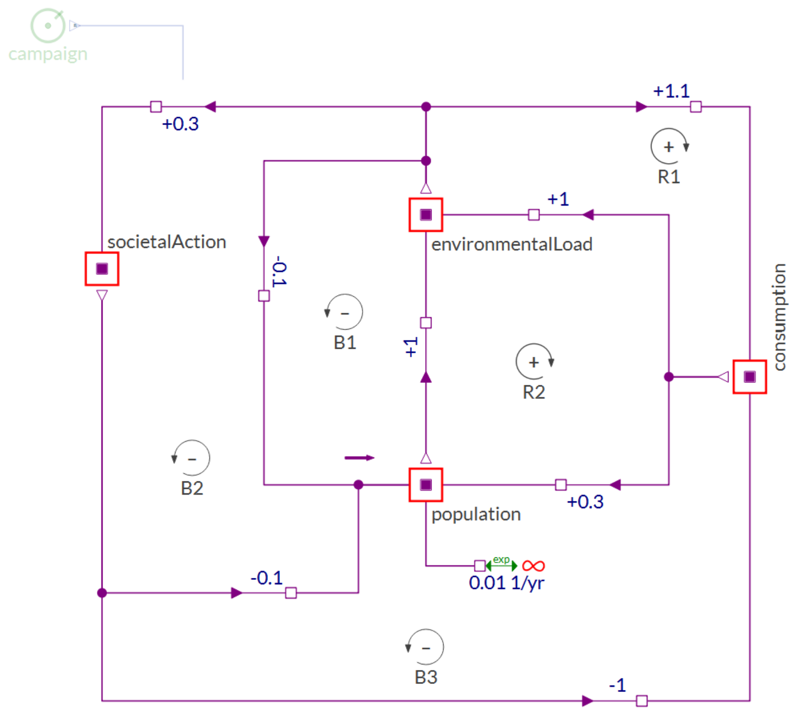
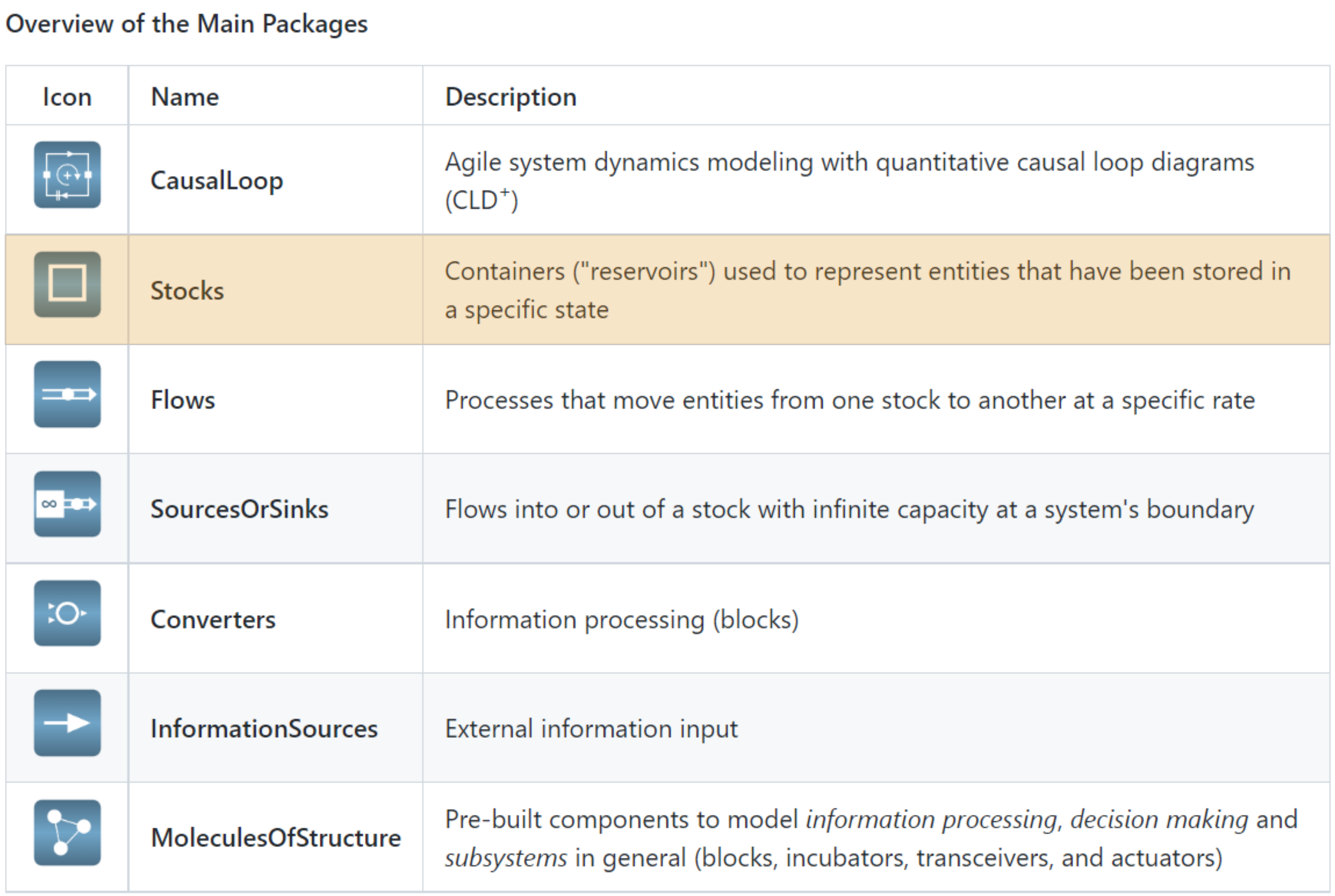


Source: https://github.com/bslMS/BusinessSimulation

Next to conventional reservoirs the BSL introduces *dynamic stocks* to finally follow up on Jay Forrester's suggestions (Industrial Dynamics, 1961)

Overview



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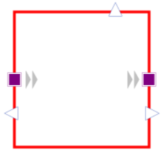
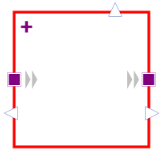
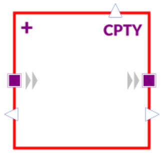


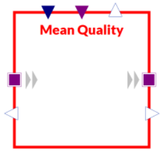
InformationLevel



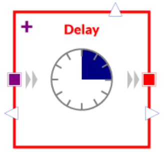
MaterialStock



CapacityRestrictedStock



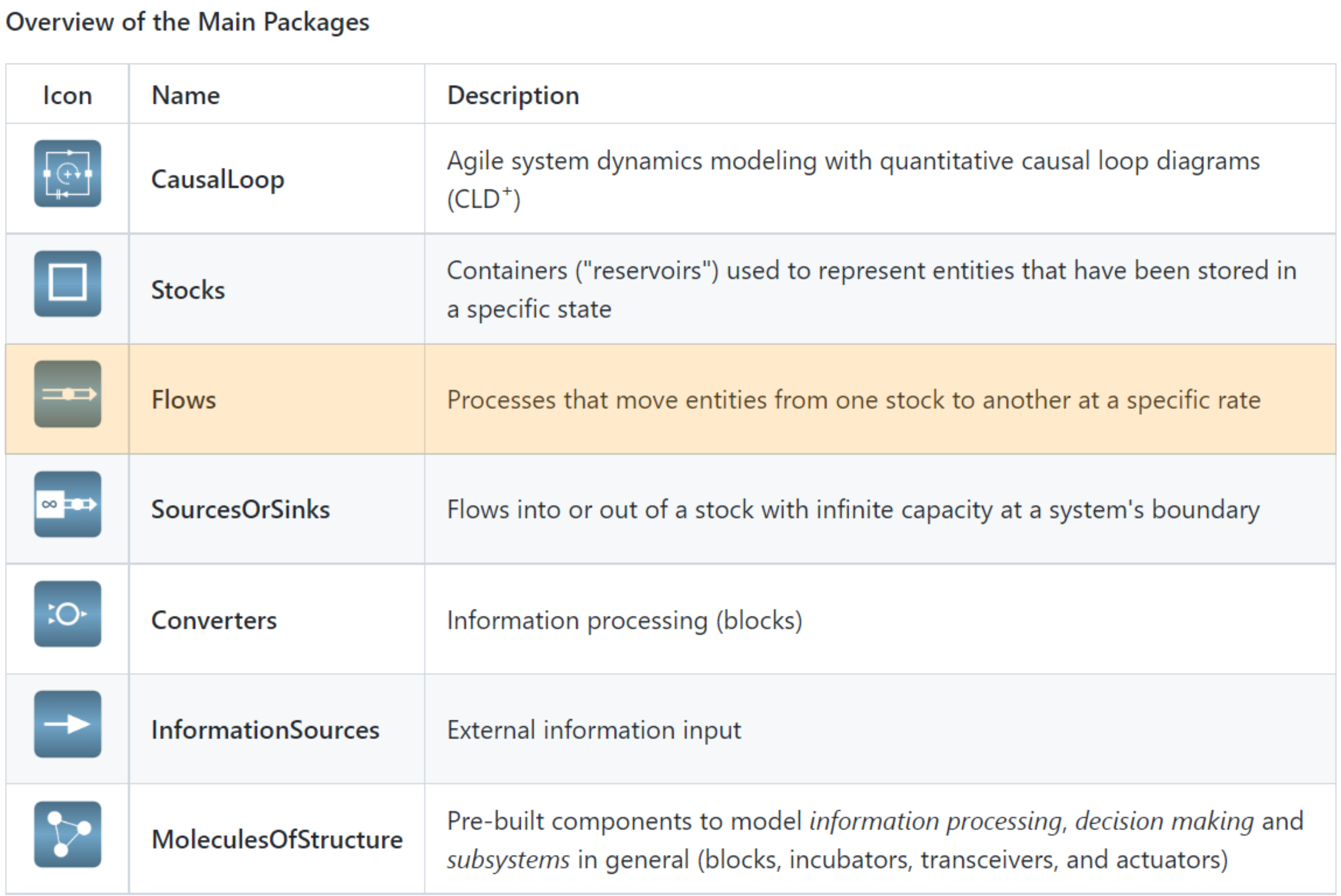
HinesCoflow



DelayN

Next to unidirectional and bi-directional flows there are also interactions in the library, which let us fit predator-pray dynamics into a single component

Overview



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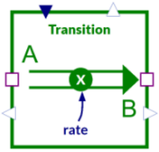
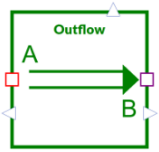
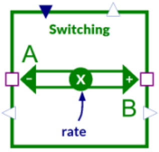


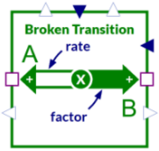
Transition



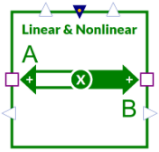
OutflowDynamicStock



Switching



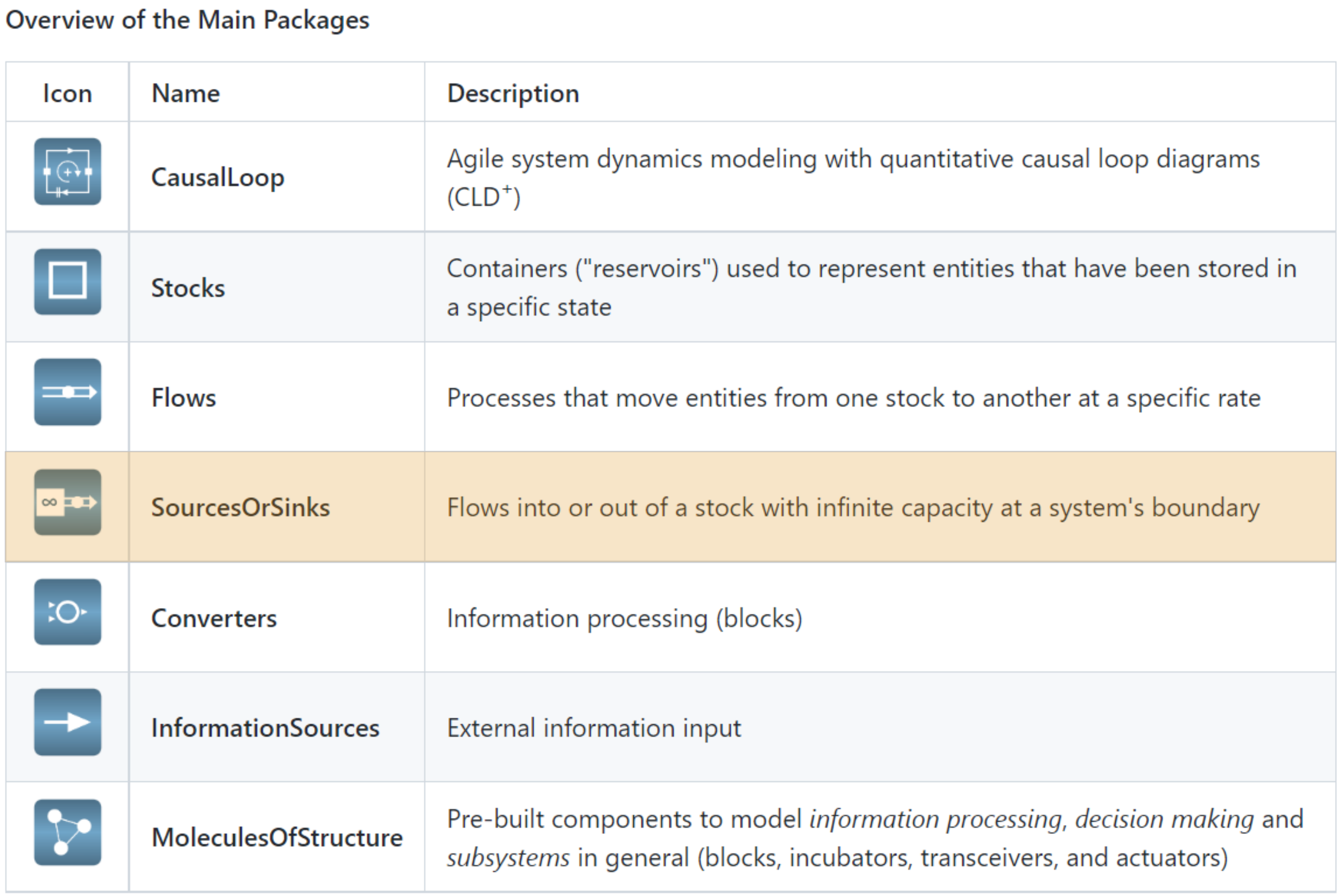
BrokenTransition



ComplexInteraction

A cloud and a flow are succinctly merged into sources or sinks to model processes of growth and decline at a model’s boundary

Overview



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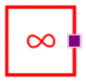
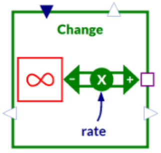
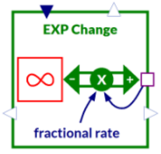


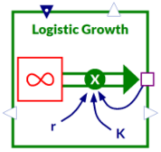
Cloud



ExogenousChange



ExponentialChange

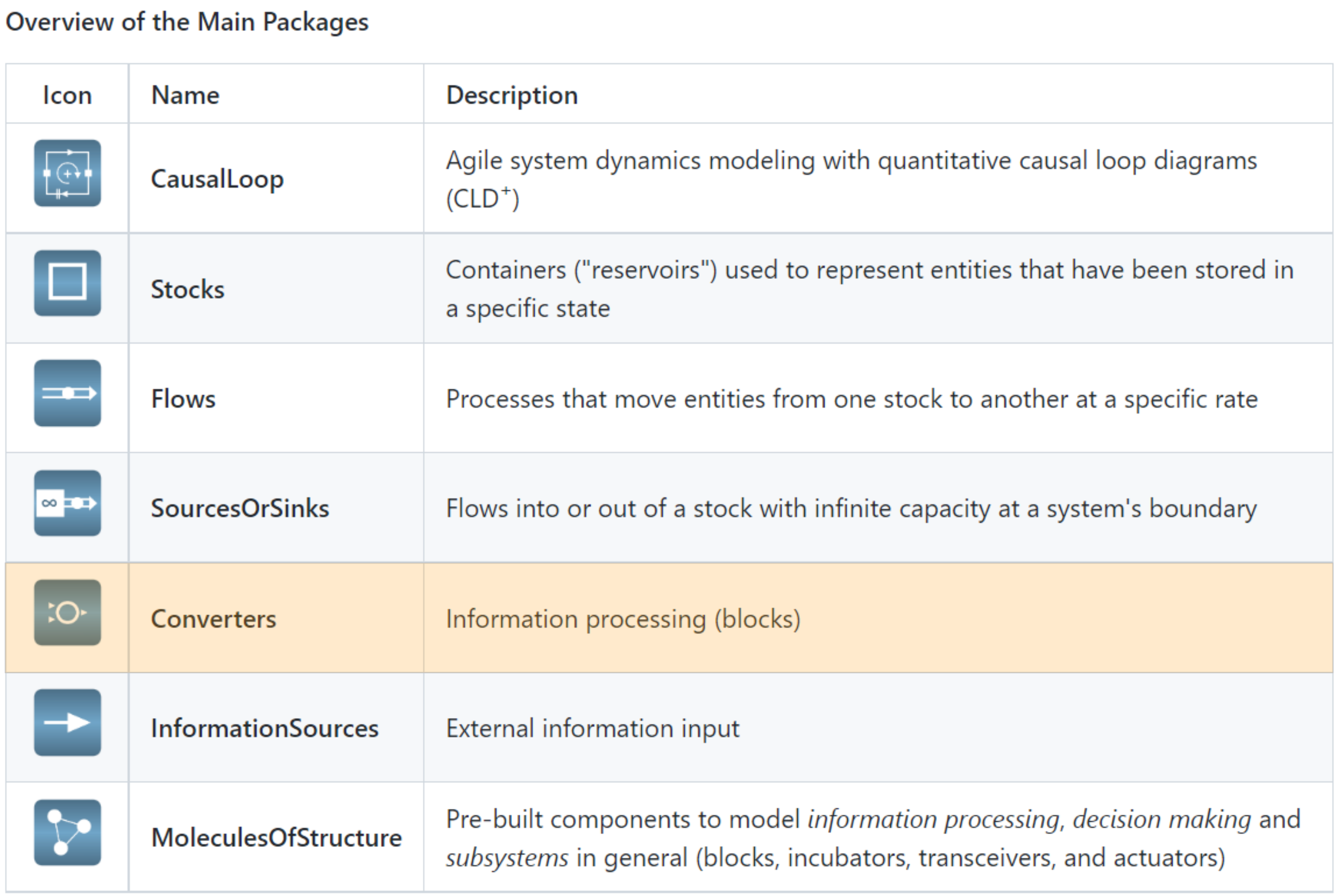


LogisticGrowth

Source: https://github.com/bslMS/BusinessSimulation

Converters are the work horses of system dynamics models and you will find a whole variety in the library

Overview



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Source: https://github.com/bslMS/BusinessSimulation

SMOOTH Discrete Delays ...

Logical Converters ...

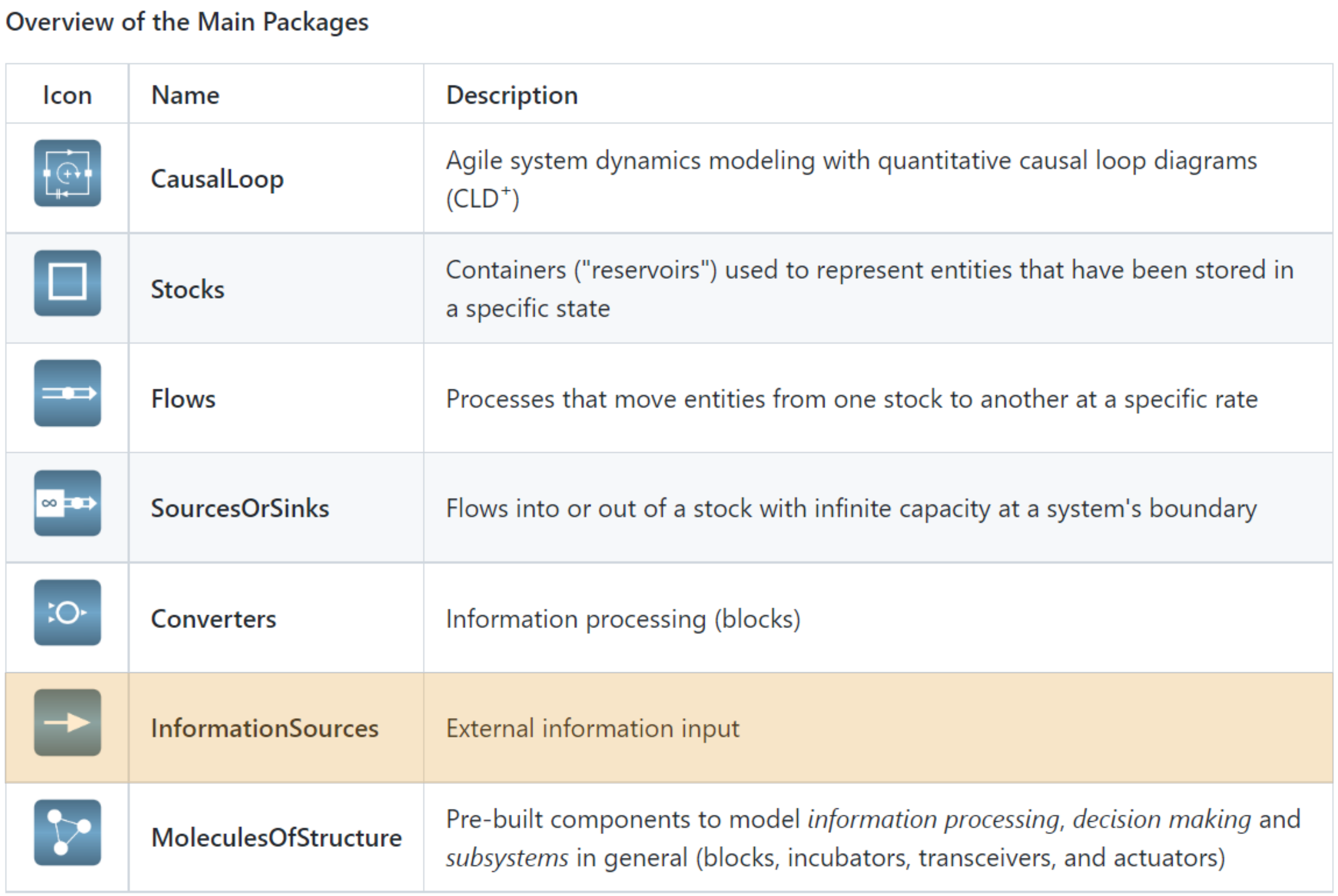
Lookup Converters ...

Vector Converters ...

Regular Converters ...

While we aim at maximal endogeneity, information inputs are needed—at least for testing

Overview



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Source: https://github.com/bslMS/BusinessSimulation

PulseInput

RampInput

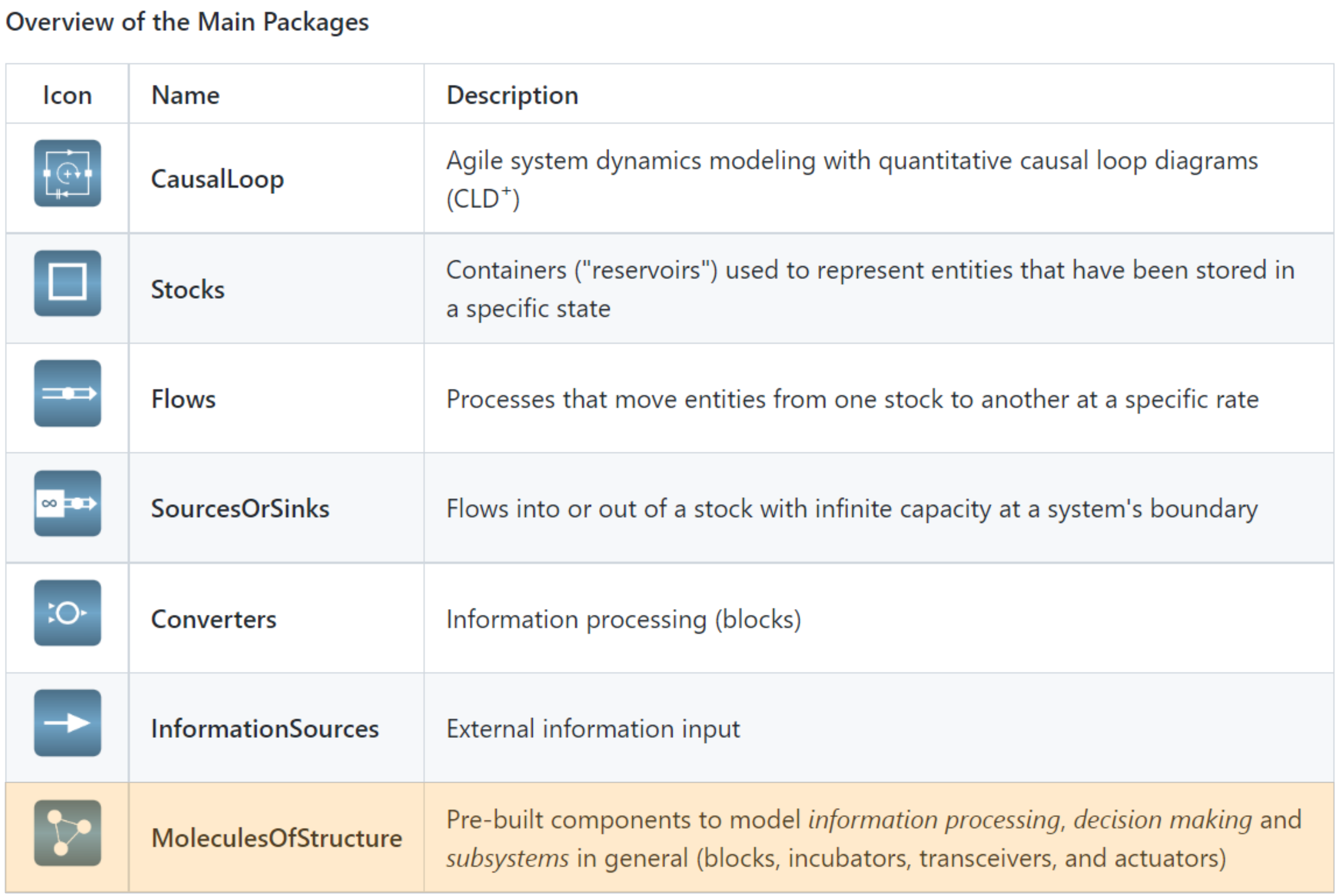
TimeInput

LinearTimeTable

ExogenousData

Widely known “Molecules of Structure” are now to be found nicely structured according to their *interfaces*, i.e., connectors

Overview



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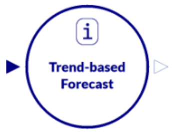
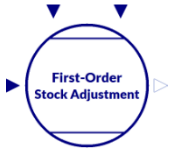
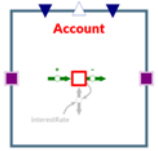


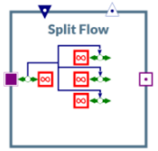
Information Processing ...



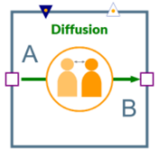
Policy ...



Incubators ...

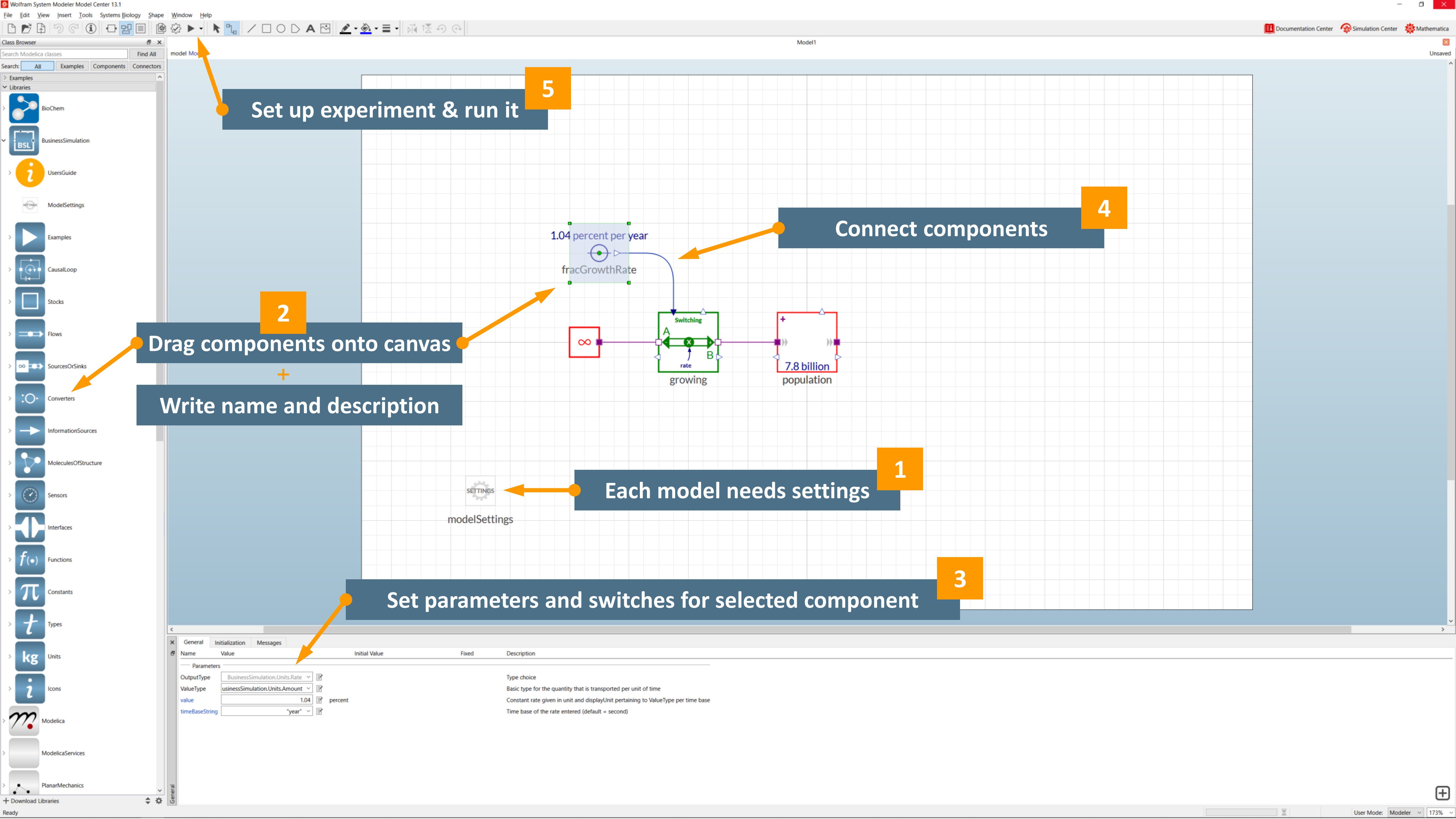


Transceivers ...



Actuators ...

Source: https://github.com/bslMS/BusinessSimulation



1 Each model needs settings

2 Drag components onto canvas
+
Write name and description

3 Set parameters and switches for selected component

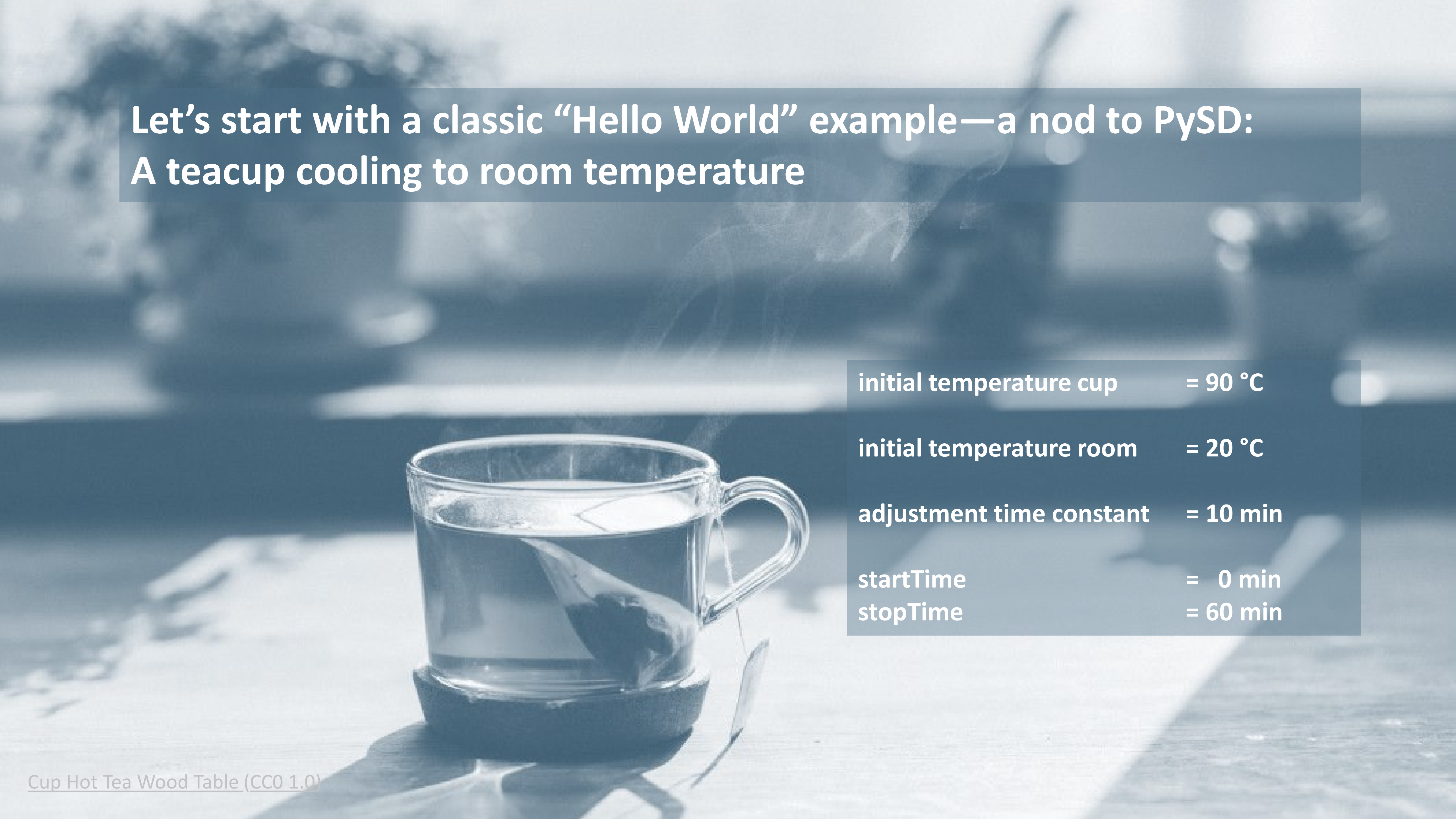
4 Connect components

5 Set up experiment & run it

General | Initialization | Messages

Name	Value		Initial Value	Fixed	Description
Parameters					
OutputType	BusinessSimulation.Units.Rate				Type choice
ValueType	usinessSimulation.Units.Amount				Basic type for the quantity that is transported per unit of time
value	1.04	percent			Constant rate given in unit and displayUnit pertaining to ValueType per time base
timeBaseString	"year"				Time base of the rate entered (default = second)

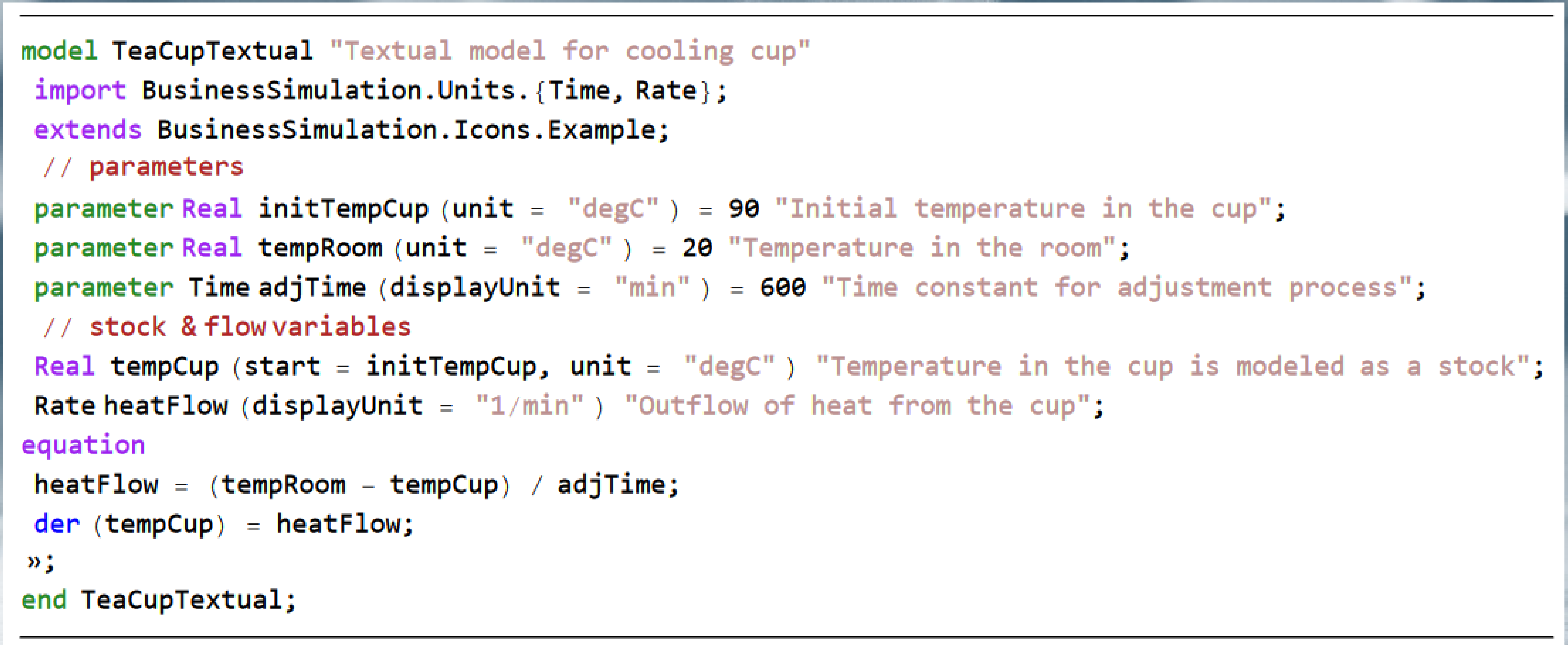
Let’s start with a classic “Hello World” example—a nod to PySD: A teacup cooling to room temperature



initial temperature cup	= 90 °C
initial temperature room	= 20 °C
adjustment time constant	= 10 min
startTime	= 0 min
stopTime	= 60 min

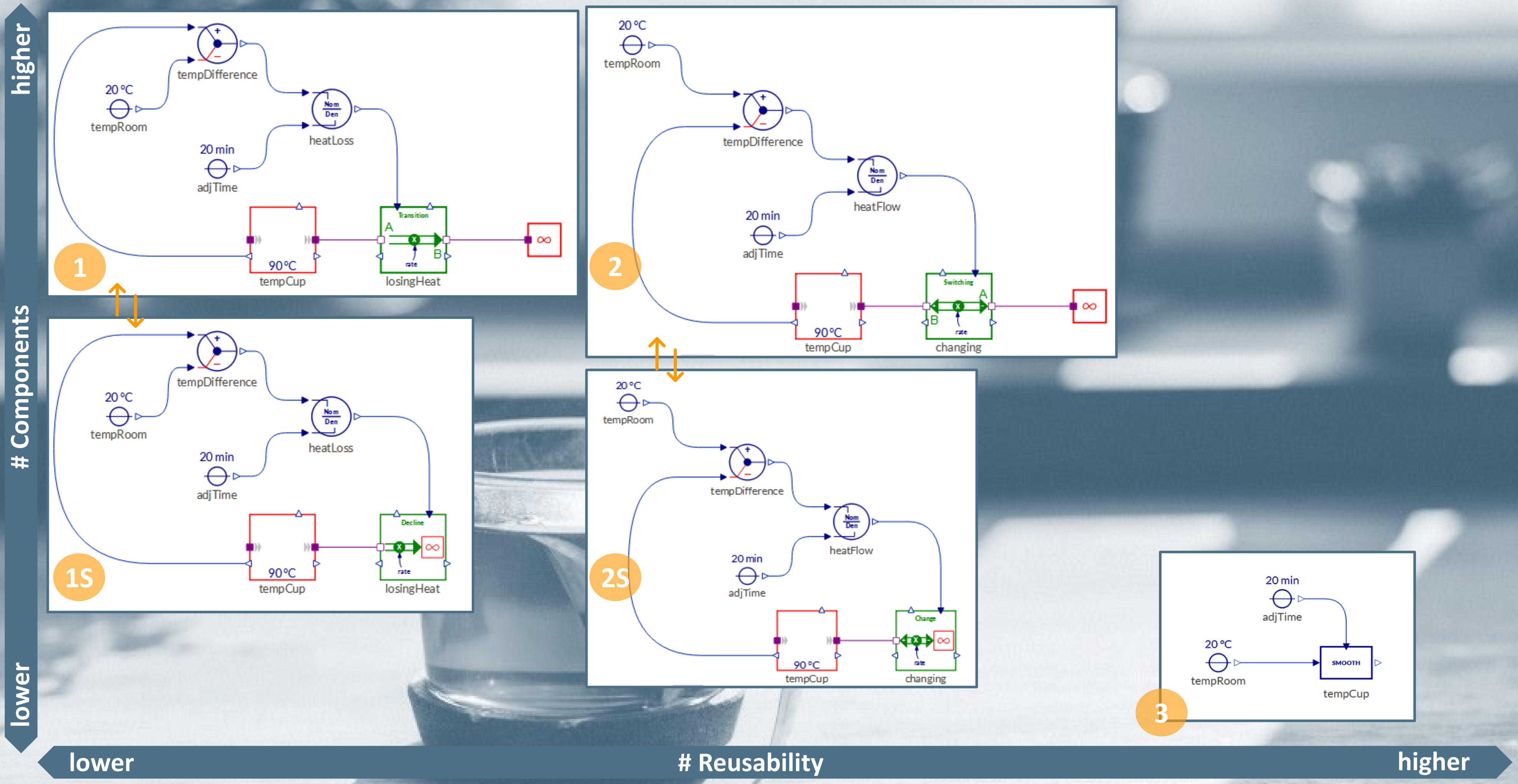
Cup Hot Tea Wood Table (CC0 1.0)

Let’s move from a straightforward textual model to a component-based version ...



```
model TeaCupTextual "Textual model for cooling cup"
 import BusinessSimulation.Units.{Time, Rate};
 extends BusinessSimulation.Icons.Example;
  // parameters
 parameter Real initTempCup (unit = "degC") = 90 "Initial temperature in the cup";
 parameter Real tempRoom (unit = "degC") = 20 "Temperature in the room";
 parameter Time adjTime (displayUnit = "min") = 600 "Time constant for adjustment process";
  // stock & flow variables
 Real tempCup (start = initTempCup, unit = "degC") "Temperature in the cup is modeled as a stock";
 Rate heatFlow (displayUnit = "1/min") "Outflow of heat from the cup";
equation
 heatFlow = (tempRoom - tempCup) / adjTime;
 der (tempCup) = heatFlow;
»;
end TeaCupTextual;
```

Cup Hot Tea Wood Table (CC0 1.0)



Cup Hot Tea Wood Table (CC0 1.0)

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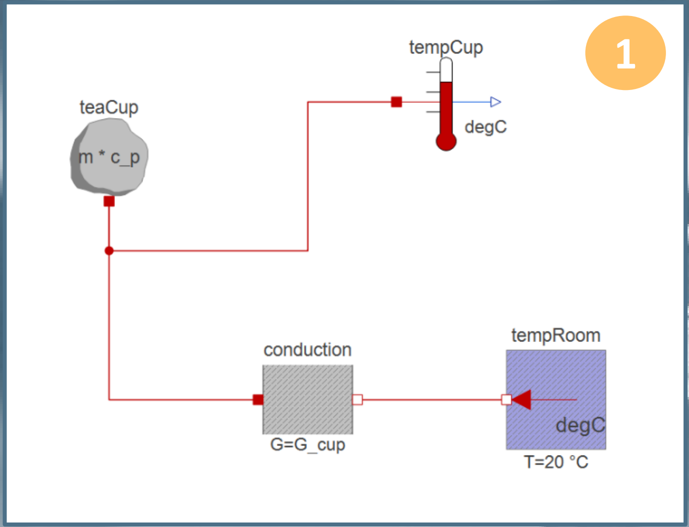
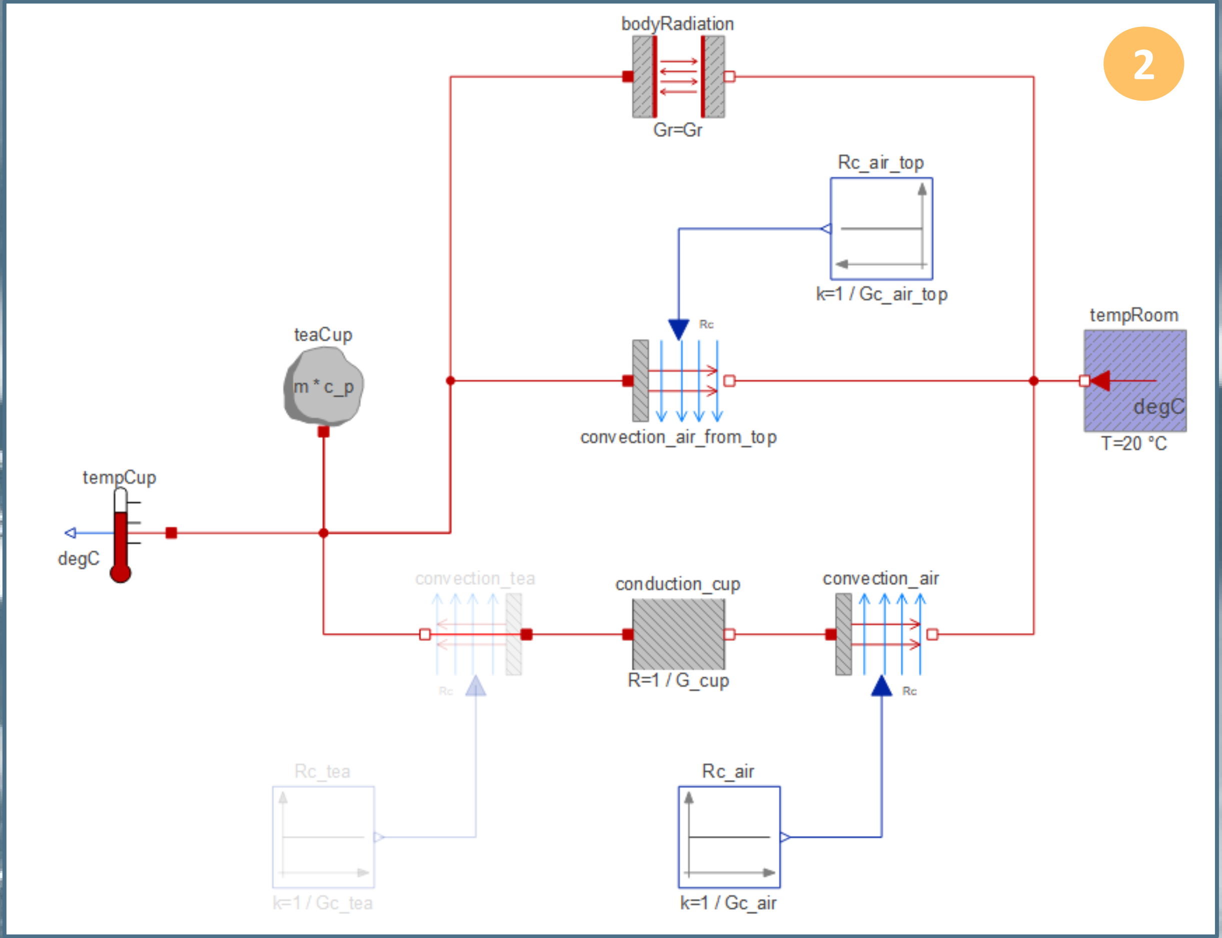
Why not consider *physical components* for physical processes?

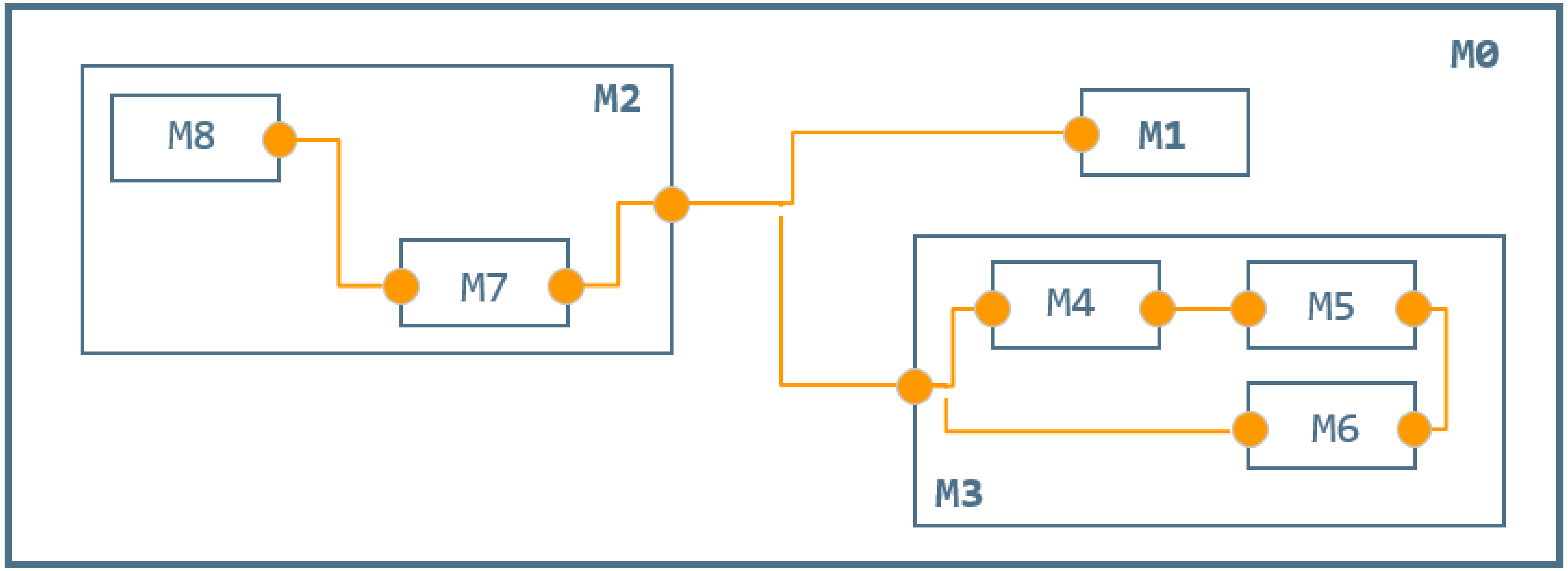




Cup Hot Tea Wood Table (CC0 1.0)

In Modelica we use pre-built models (components), which exchange information or matter via interfaces (connectors) in a nested fashion

Hierarchical Modeling



For more background information have a look at my poster presentation: https://youtu.be/UX0M_DtS1vs

In the Business Simulation Library there are four basic connectors: Causal input/output connectors, and acausal stock and flow ports

Connectors

Causal Connectors for Information Exchange

▶ `RealInput`

▷ `RealOutput`

Acausal Connectors for Physical Exchange

▣ `StockPort`

□ `FlowPort`

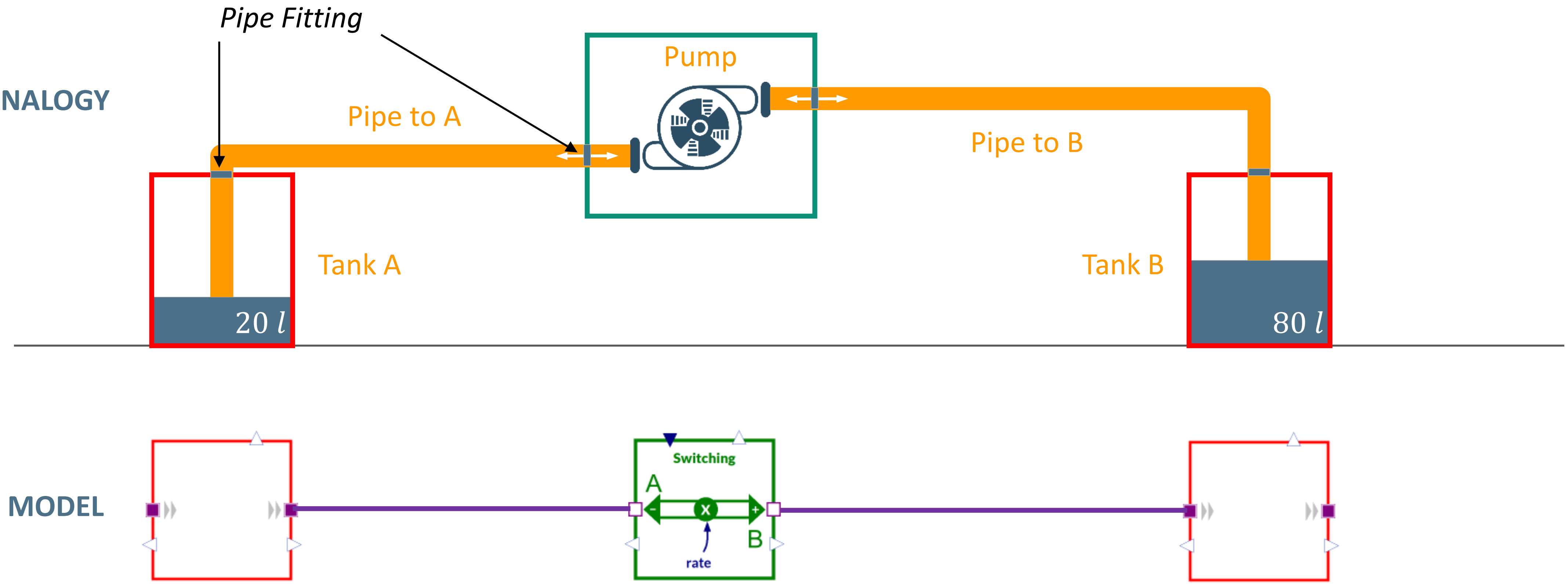
A dot inside these icons will indicate a multi-connector (e.g., a vector version)

In SD we love to use physical analogies like reservoirs, pumps, and pipes. But why should a pipe or its *fittings* be “causal”?

Acausal Connectors (1)

PHYSICAL ANALOGY

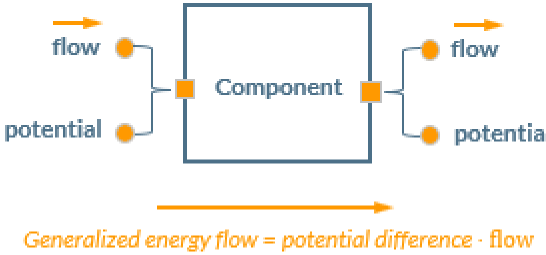
COMPUTER MODEL

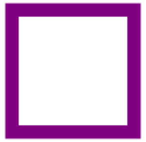


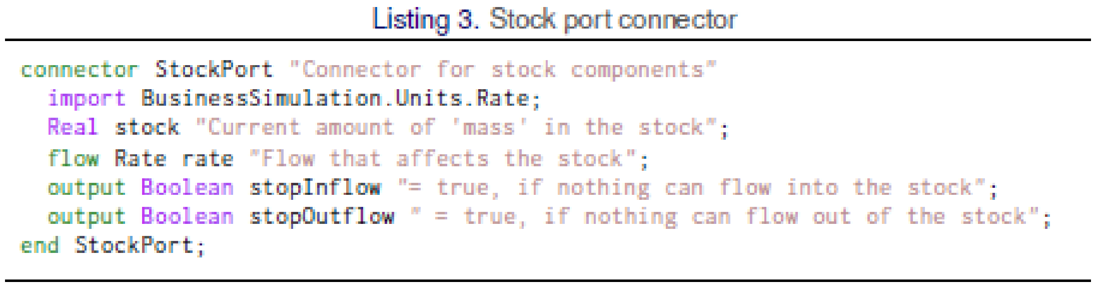
Acausality promotes reusability of connectors and components in physical modeling.

Each acausal connector has two variables: a *flow* and a *potential*—as we usually don't track energy flows in SD we replace *potential* with *stock*

Acausal Connectors (2)

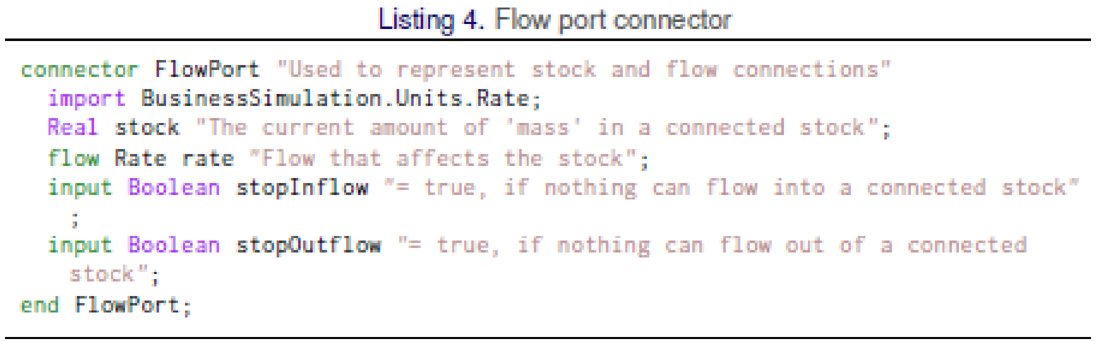






Listing 3. Stock port connector

```
connector StockPort "Connector for stock components"
  import BusinessSimulation.Units.Rate;
  Real stock "Current amount of 'mass' in the stock";
  flow Rate rate "Flow that affects the stock";
  output Boolean stopInflow "= true, if nothing can flow into the stock";
  output Boolean stopOutflow " = true, if nothing can flow out of the stock";
end StockPort;
```



Listing 4. Flow port connector

```
connector FlowPort "Used to represent stock and flow connections"
  import BusinessSimulation.Units.Rate;
  Real stock "The current amount of 'mass' in a connected stock";
  flow Rate rate "Flow that affects the stock";
  input Boolean stopInflow "= true, if nothing can flow into a connected stock"
    ;
  input Boolean stopOutflow "= true, if nothing can flow out of a connected
    stock";
end FlowPort;
```

Flows will observe Boolean flags for restricted stocks, e.g., material stocks cannot be drained below zero.

In Modelica we are basically writing a system of differential-algebraic *equations* in peacemeal fashion, so that it can be solved

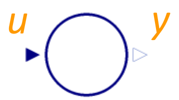
Equation Puzzle

CONNECTORS

EQUATIONS

CONVERTERS

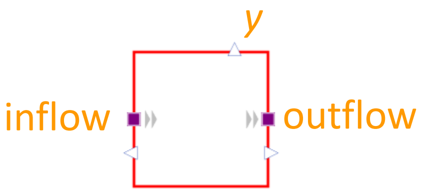
... *transform information input*



$$y = f(u)$$

STOCKS

... solve ODE for internal state



$$\mathrm{der}(x) = \mathrm{inflow.rate} + \mathrm{outflow.rate}$$

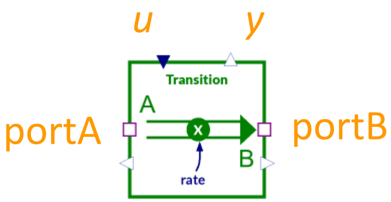
$$\mathrm{inflow.\,stock} = x$$

$$\mathrm{outflow.\,stock} = x$$

$$y = \mathrm{inflow.stock}$$

FLOWS

... set rates of transition



$$\mathrm{portA.rate} = u$$

$$\mathrm{portB.rate} = -\mathrm{portA.rate}$$

$$y = \mathrm{portA.rate}$$

Note: A *positive* rate per definition flows <u>into</u> the component in Modelica.

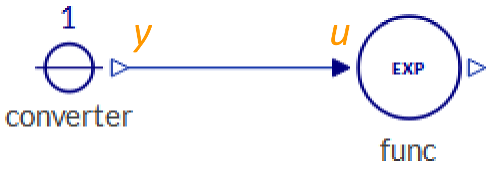
Connections introduce equations behind the scenes—the equations for acausal connections arise from Kirchhoff’s Laws

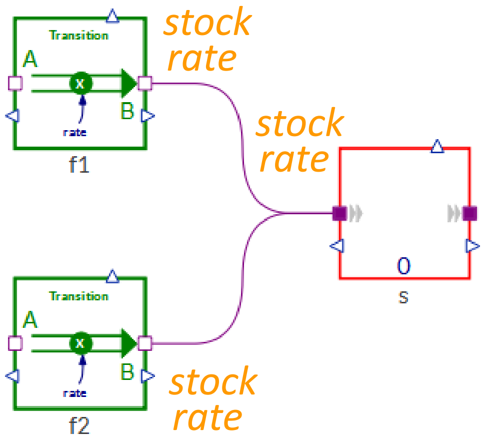
Connect-Equations

Connect-Equation (Causal)

Connect-Equations (Acausal)

DIAGRAM





TEXT

```
connect(converter.y, func.u)
```

```
connect(f1.portB, s.inflow)
connect(f2.portB, s.inflow)
```

EQUATIONS

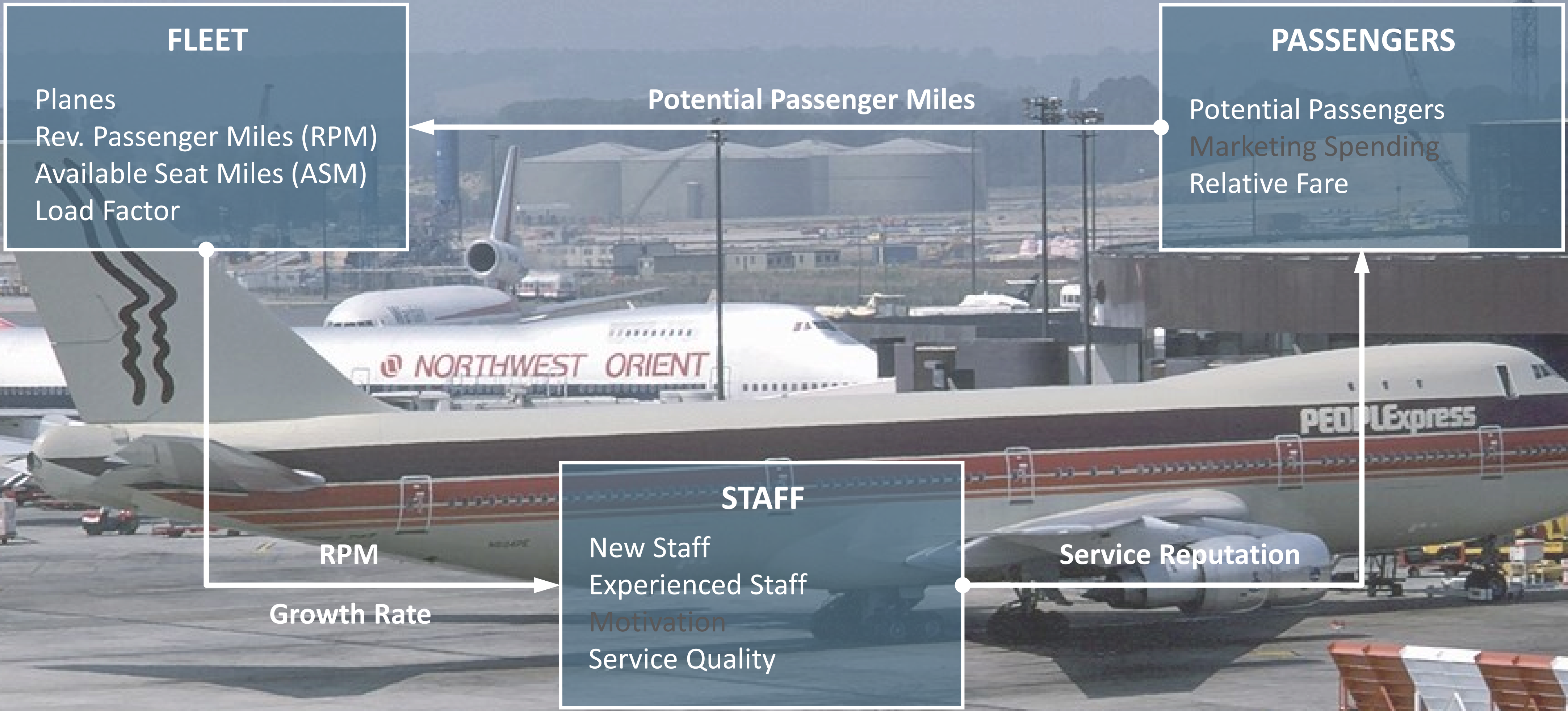
$$\mathbf{converter.y} = \mathrm{func.u}$$

$$\begin{aligned} \mathbf{f1.portB.rate} + \mathbf{f2.portB.rate} + \mathrm{s.rate} &= 0 \\ \mathrm{f1.portB.stock} &= \mathbf{s.stock} \\ \mathrm{f2.portB.stock} &= \mathbf{s.stock} \end{aligned}$$

Known values in equations printed in bold face, i.e., flows set rates and stocks determine their internal state from solving `der(x) = sum of flows`

Building More Complex Models

... in a way that supports collaboration and avoids repetition



FLEET

Planes
Rev. Passenger Miles (RPM)
Available Seat Miles (ASM)
Load Factor

Potential Passenger Miles

PASSENGERS

Potential Passengers
Marketing Spending
Relative Fare

RPM

Growth Rate

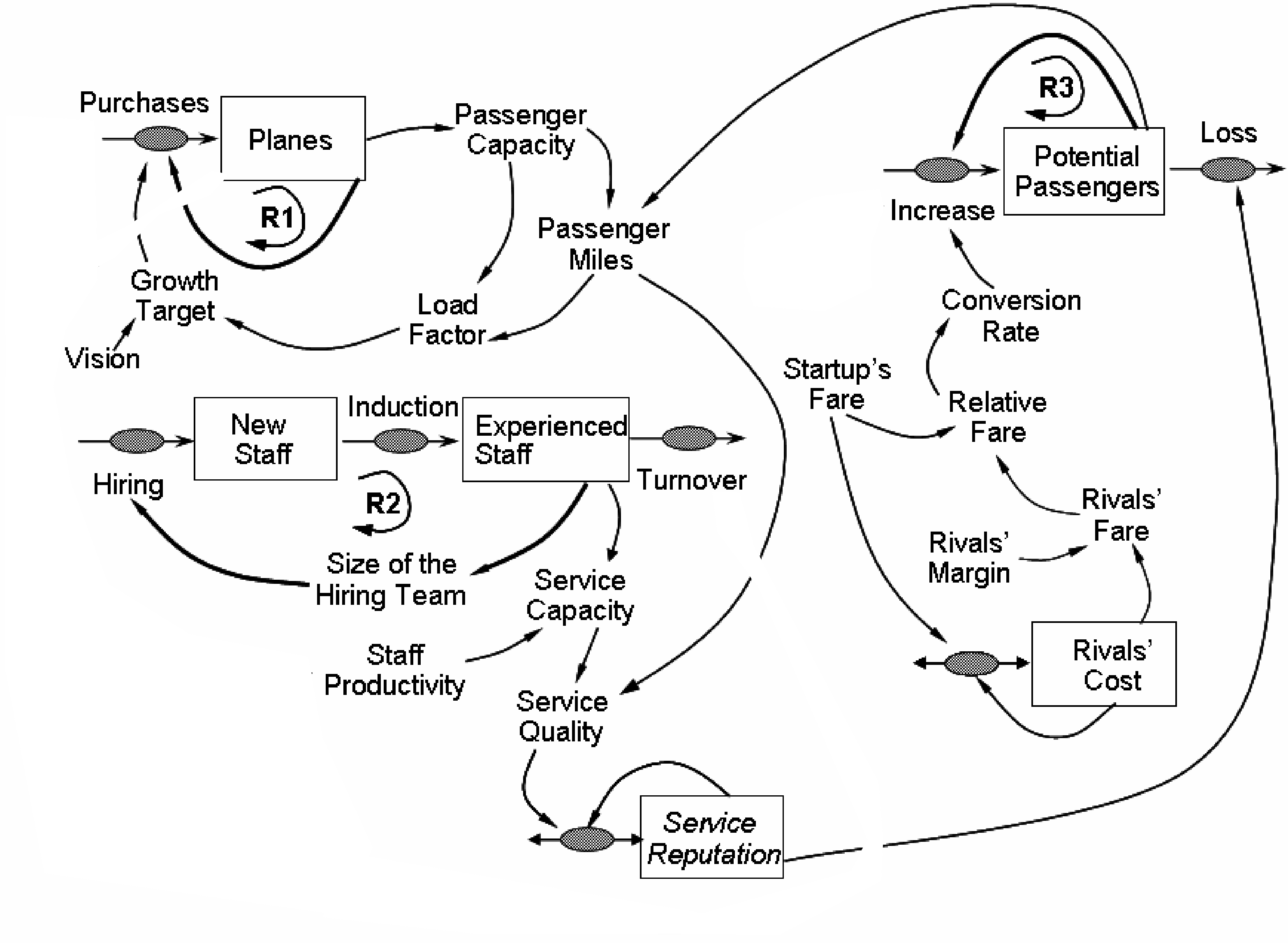
STAFF

New Staff
Experienced Staff
Motivation
Service Quality

Service Reputation

J.D.W. Morecroft, "System Dynamics, RBV and Behavioural Theories of Firm Performance: Lessons from People Express," *Proceedings of the 26th International Conference of the System Dynamics Society*, 2008.

Eduard Marmet, https://wolfr.am/1SbLpZqTI, CC BY-SA 3.0
A Boeing 747 of People Express at London Gatwick Airport (June 1983).

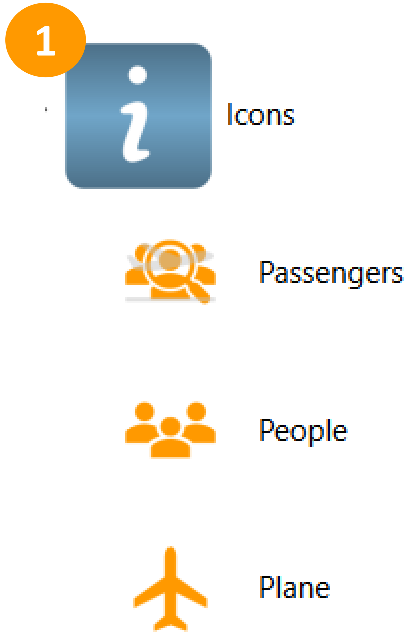


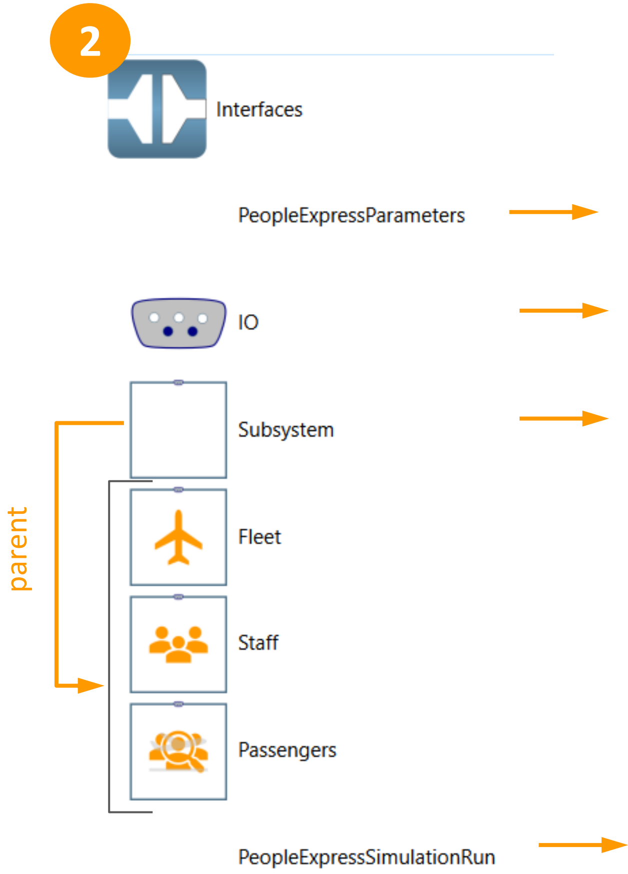
J.D.W. Morecroft, “System Dynamics, RBV and Behavioural Theories of Firm Performance: Lessons from People Express,” *Proceedings of the 26th International Conference of the System Dynamics Society*, 2008.

Eduard Marmet, https://wolfr.am/15bLpZqTI, CC BY-SA 3.0
A Boeing 747 of People Express at London Gatwick Airport (June 1983).

After creating some classes for icons we establish partial models for subsystems and a central I/O connector

Interfaces

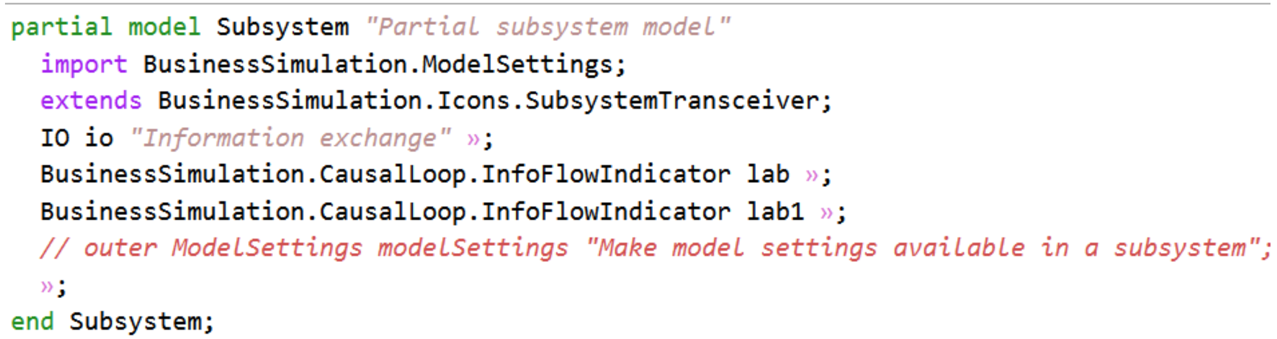




PeopleExpressParameters → global parameters

IO → full list of vars exchanged between subsystems

Subsystem →

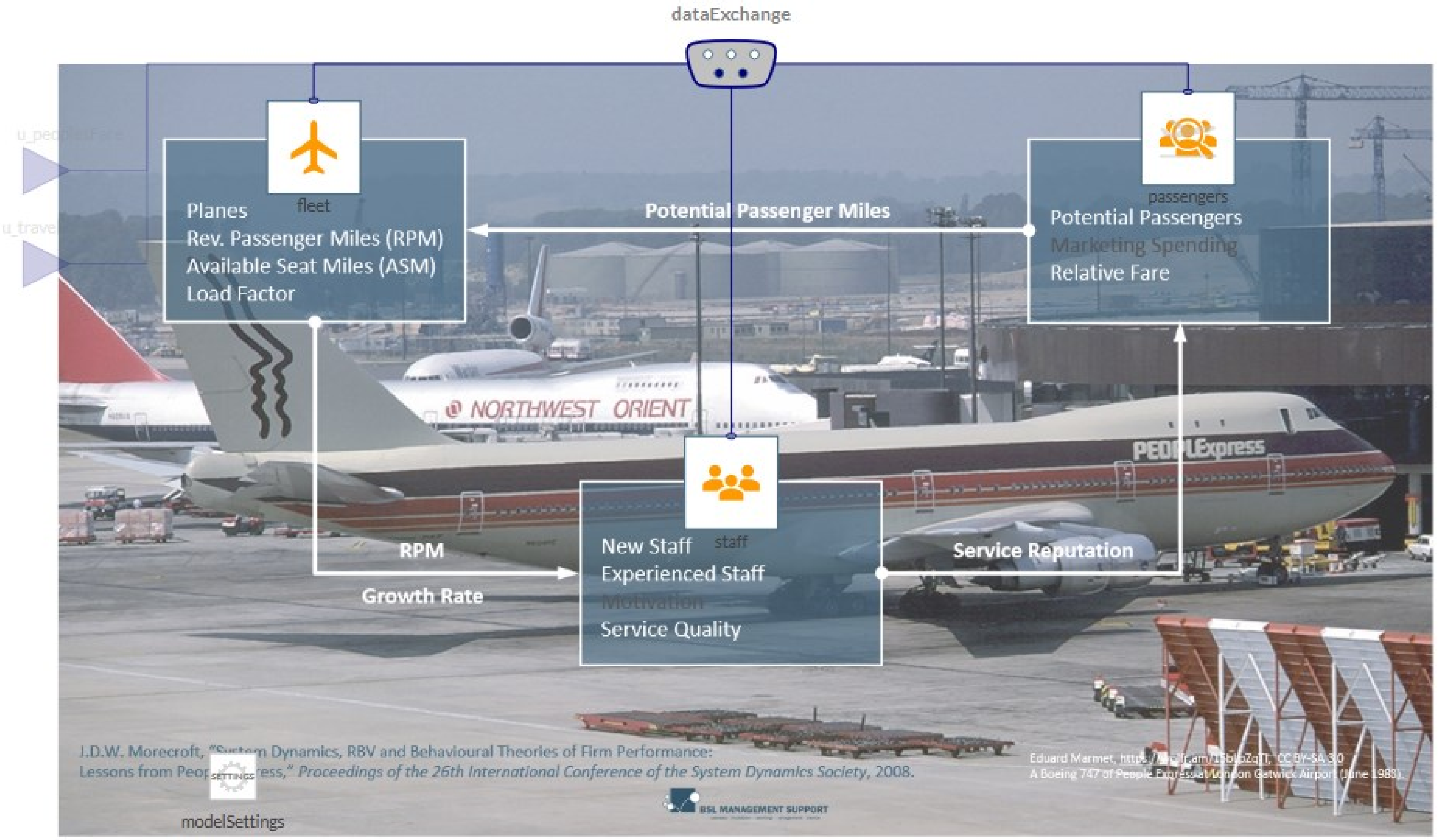


```
partial model Subsystem "Partial subsystem model"
  import BusinessSimulation.ModelSettings;
  extends BusinessSimulation.Icons.SubsystemTransceiver;
  IO io "Information exchange" »;
  BusinessSimulation.CausalLoop.InfoFlowIndicator lab »;
  BusinessSimulation.CausalLoop.InfoFlowIndicator lab1 »;
  // outer ModelSettings modelSettings "Make model settings available in a subsystem";
  »;
end Subsystem;
```

PeopleExpressSimulationRun → Model Settings and experiment annotation

The final model looks exactly like our initial subsystem diagram—a central dataExchange means that we just need *n* connections to have full exchange

BaseRun



J.D.W. Morecroft, "System Dynamics, RBV and Behavioural Theories of Firm Performance: Lessons from People Express," *Proceedings of the 26th International Conference of the System Dynamics Society*, 2008.

Eduard Marmet, https://flic.kr/p/15bUbZqTT, CC BY-SA 3.0
A Boeing 747 of People Express at London Gatwick Airport (June 1983).

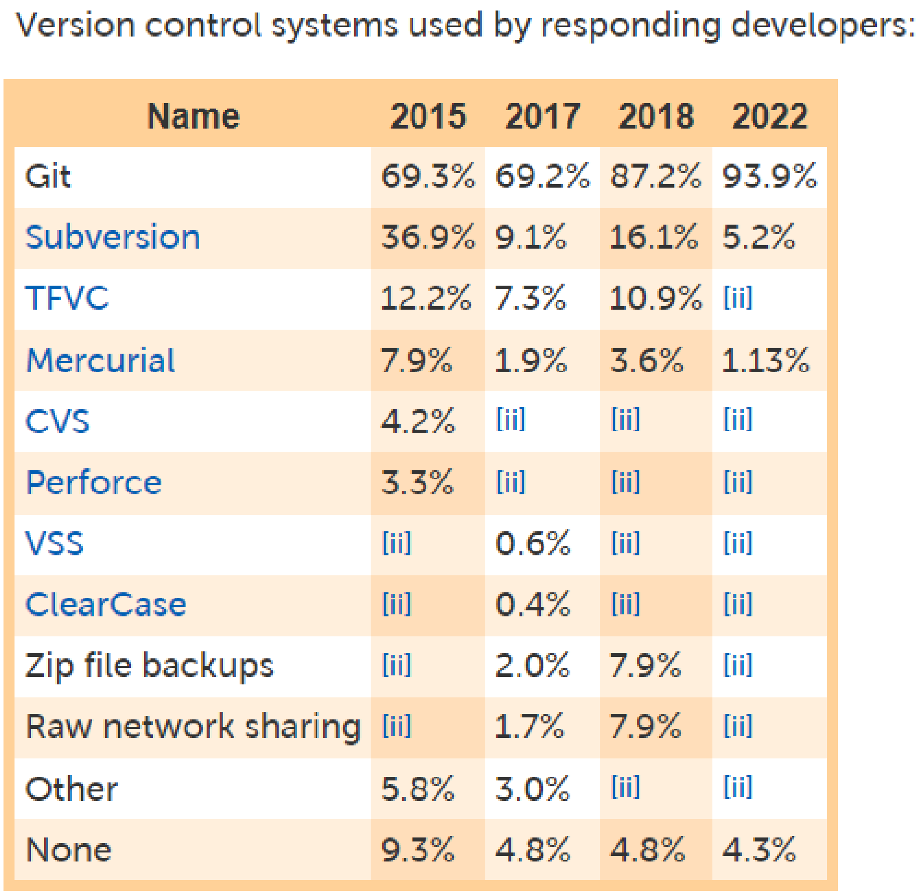
`ISDC2022_Workshops.Examples.PeopleExpress.BaseRun`

Collaboration & Deployment

Using Git and GitHub

A Stack Overflow survey shows that Git really is the main tool used by software developers for version control and collaboration

Version Control Choices



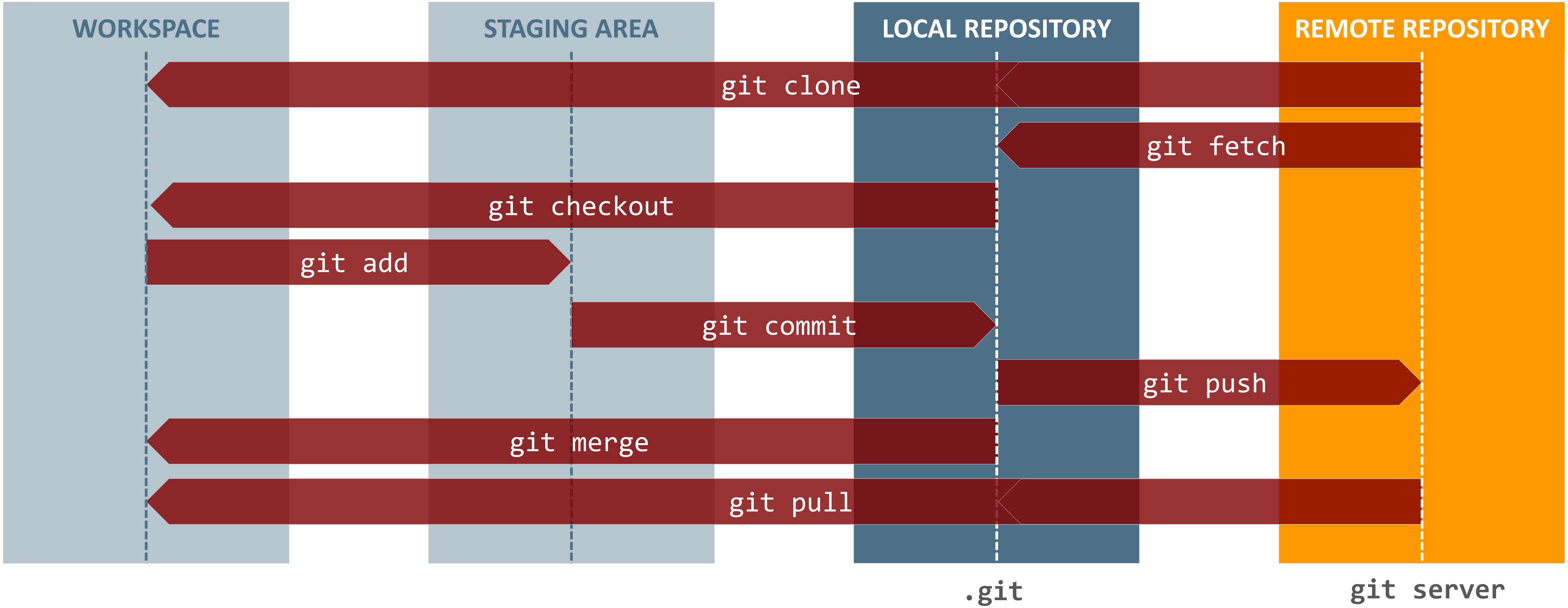
Version control systems used by responding developers:

Name	2015	2017	2018	2022
Git	69.3%	69.2%	87.2%	93.9%
Subversion	36.9%	9.1%	16.1%	5.2%
TFVC	12.2%	7.3%	10.9%	[ii]
Mercurial	7.9%	1.9%	3.6%	1.13%
CVS	4.2%	[ii]	[ii]	[ii]
Perforce	3.3%	[ii]	[ii]	[ii]
VSS	[ii]	0.6%	[ii]	[ii]
ClearCase	[ii]	0.4%	[ii]	[ii]
Zip file backups	[ii]	2.0%	7.9%	[ii]
Raw network sharing	[ii]	1.7%	7.9%	[ii]
Other	5.8%	3.0%	[ii]	[ii]
None	9.3%	4.8%	4.8%	4.3%

Source: Wikipedia contributors. "Git.“ Wikipedia, The Free Encyclopedia, 28 Jun. 2022.

Local changes are *staged*, then *committed*, and finally *pushed* into the remote repository; branches typically get *merged* upon a *pull request*

Git Workflows

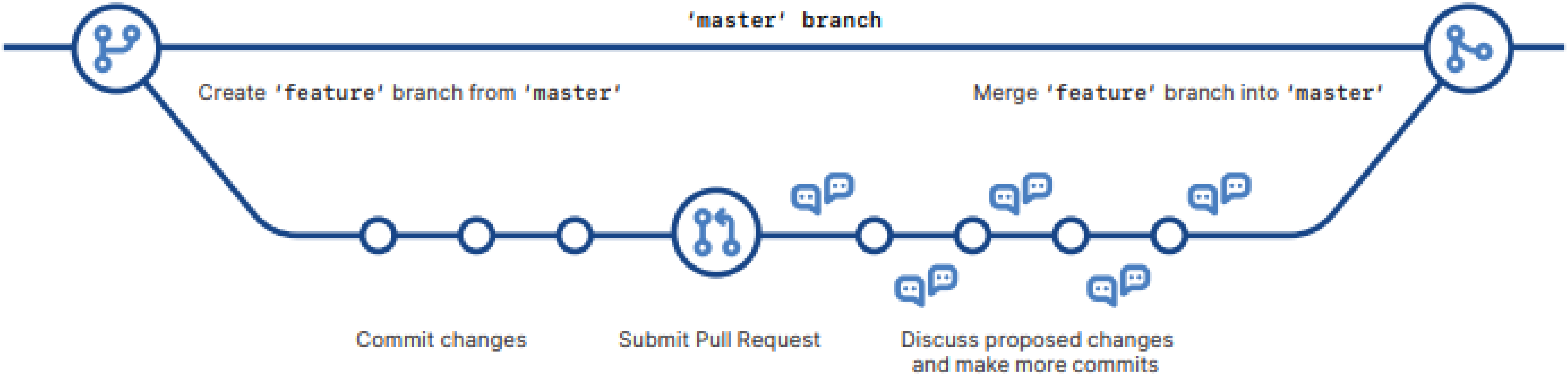


Source: https://ndpsoftware.com/git-cheatsheet.html#loc=index

Branching—next to speed and its distributed organization—is what makes Git stand out among version control solutions

Branches

‘main’ *preferable for obvious reasons...*



Source: GitHub. “Git Cheat Sheet.” Link: https://training.github.com/downloads/github-git-cheat-sheet.pdf

After setting up a local repository we can push this to a central repository on a git server

Set up Git

STEP 1: Set up a local repository for a project

1. Prevent empty directories from being ignored by adding an empty **`.gitignore`** file.
2. Ignore certain files (e.g., binaries) and directories by explicitly listing these in the **`.gitignore`** file in the root directory.
3. Configure Git to handle line endings in a compatible fashion between operating systems:

```
git config --global core.autocrlf true   (Windows)
git config --global core.autocrlf input  (Unix)
```

4. Setup a repository in the root directory and import files:

```
git init
git add .
git commit –m “initial commit”
```

STEP 2: Prepare remote bare repository for distribution

1. Create a new public or private repository on a git server (e.g., GitHub, GitLab, Bitbucket) that should be completely empty (no README).
2. Push local repository to remote (shortname: **`origin`**) and make the remote main branch the tracking reference:

```
git remote add origin <url>
git push –set-upstream origin main
```

3. All members of the development team can now clone the remote repository:

```
git clone <url>
```

Turn to https://git-scm.com/ for documentation and reference.

VCF

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