How data assimilation can help in the initialization of Modelica models?

February 6th, 2024

EDF R&D

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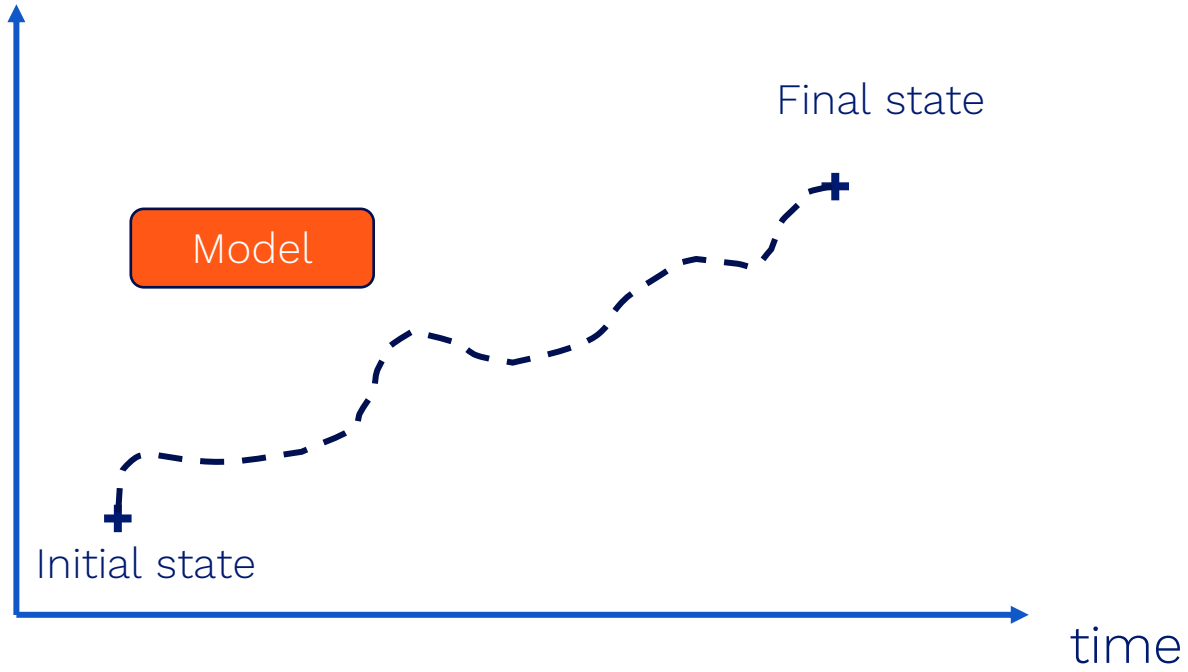
What is the initialization of a Modelica model?

- Model initialization consists in finding the **initial state** of the system which have to:
  - Verify the equations of the model
  - be physically acceptable

In practice, it requires a deep knowledge on the system's physics and rare expertise



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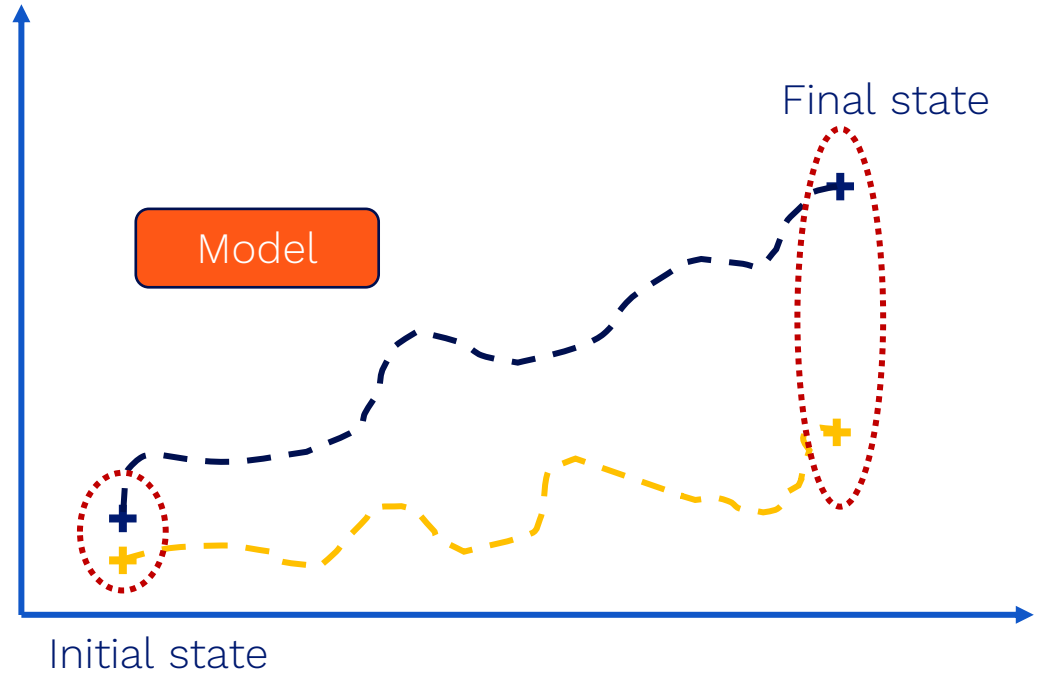


The correct estimation of the initial state of the system is important to be able to get **reliable simulation results** from the Modelica model

What is the initialization of a Modelica model?

- From the equational point of view, the system model is formulated as a set of DAEs

$$\begin{cases} \dot{x} = f(x, a, p) \\ 0 = g(x, a, p) \\ y = h(x, a, p) \end{cases}$$

x is the vector of dynamic states

a is the vector of algebraic states

p is the vector of parameters and inputs

- Model initialization consists in finding the state i.e. the triplet (x, a, p) such that $y = y_{measured}$ at time $t = t_0$

1. Why the initialization of Modelica models is difficult and how Data Assimilation can help in this process?

2. Use of Data Assimilation for industrial applications

3. Further developments

1

Why the initialization of Modelica models is difficult and how Data Assimilation can help in this process?

Current initialization of Modelica models

- **Current method** consists in solving the initial **stationary system** :

$$\begin{cases} \dot{x} = f(x,a,p) \\ 0 = g(x,a,p) \\ y = h(x,a,p) \end{cases}$$

With

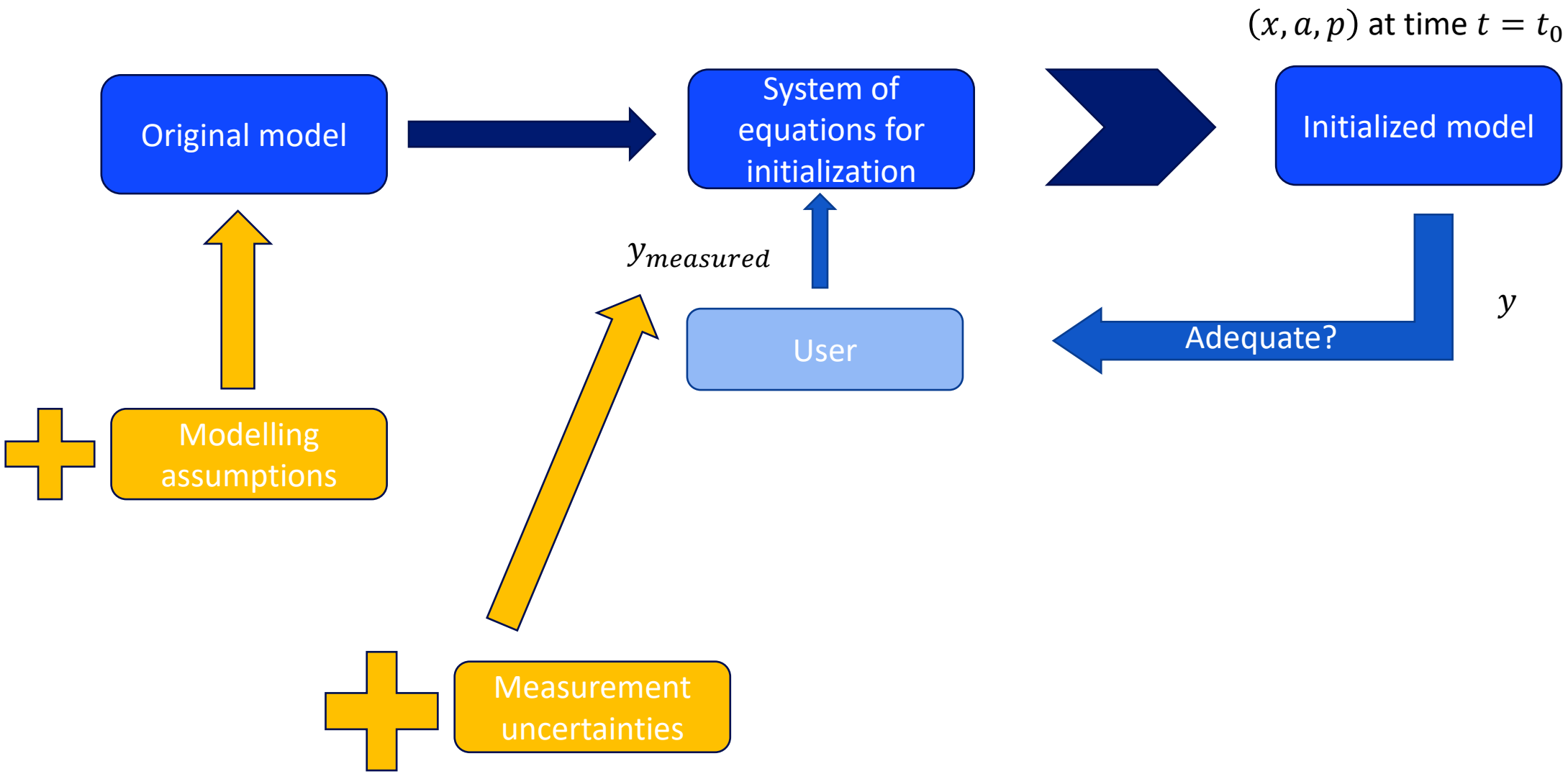
$$\begin{aligned} y &= y_{measured} \\ \dot{x} &= 0 \end{aligned}$$

$$\xrightarrow{\text{yields}} \begin{cases} 0 = f(x,a,p) \\ 0 = g(x,a,p) \\ y_{measured} = h(x,a,p) \end{cases}$$

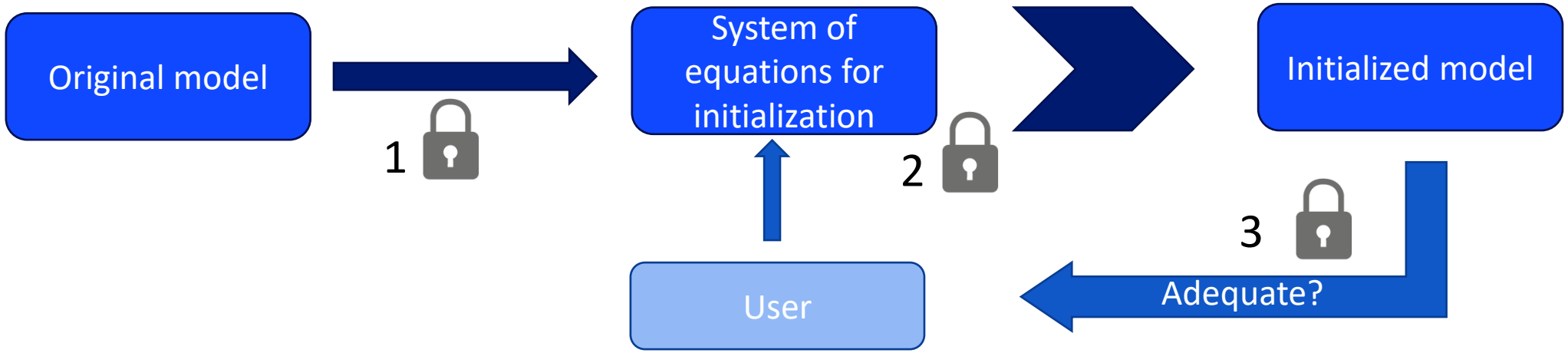
- Initialization is made on a stationary point to ensure the physical consistency of the solution
- The problem is to compute the stationary state (x,a,p) such that $y = y_{measured}$
- x and a are unknown and the model has been written with the assumption that p is known (p being all model inputs such as parameters, boundary conditions…)
- In fact, p is mostly unknown. Without loss of generality, one can assume that all p are unknown.
  - If all p are unknown, to have a square system, size of $y_{measured}$ should be equal to size of p

$sizeof(y_{measured}) = sizeof(p)$	$sizeof(y_{measured}) < sizeof(p)$	$sizeof(y_{measured}) > sizeof(p)$
Never happens	Additional assumptions must be made	Which measurements must be eliminated and why?

Why initialization of Modelica models is difficult?



Why initialization of Modelica models is difficult?

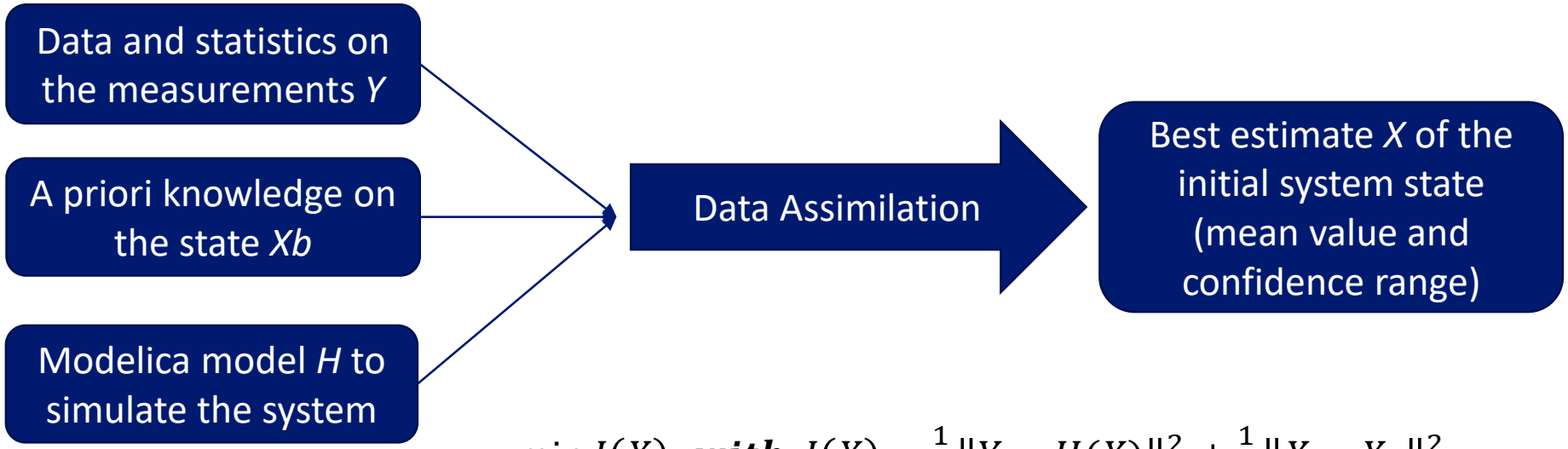


Three difficulties can be identified:

1. Extract equations required for initialization and determine state variables
2. Find a numerical solution for the system of equations for initialization
3. Ensure that the calculated initial state is as close as possible to reality

Why data assimilation?

- In practice, the number of states variables to be estimated often far exceeds the number of known variables or targets
- Data assimilation (DA) classical goal is to cope with this difficulty, by solving the initial state estimation as an optimization problem using measurements or targets ==> DA is used here for parameter estimation (and not for dynamical state estimation)



$$\min_X J(X) \quad \textbf{with} \quad J(X) = \frac{1}{2}\|Y - H(X)\|_R^2 + \frac{1}{2}\|X - X_b\|_B^2$$

(x, a, p) $\quad y_{measured}$ $\quad y$

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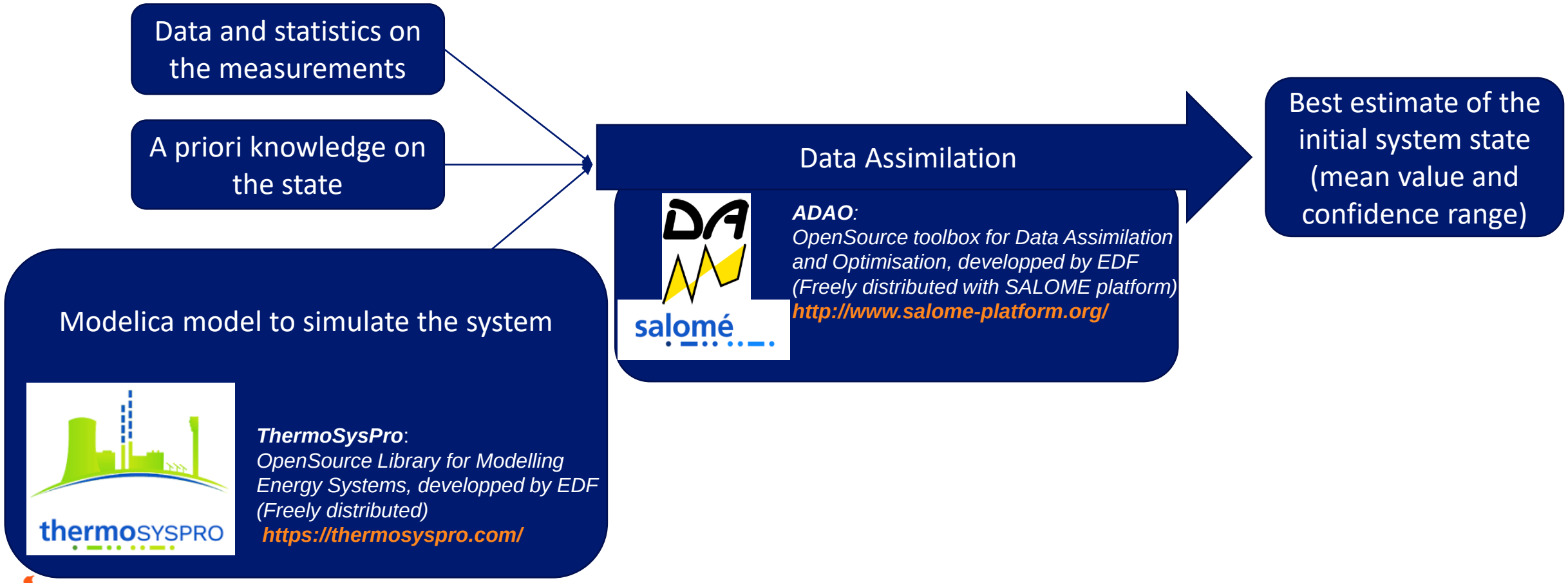
Use of Data Assimilation for industrial applications

1. Framework for our industrial application

==> *Generic view*

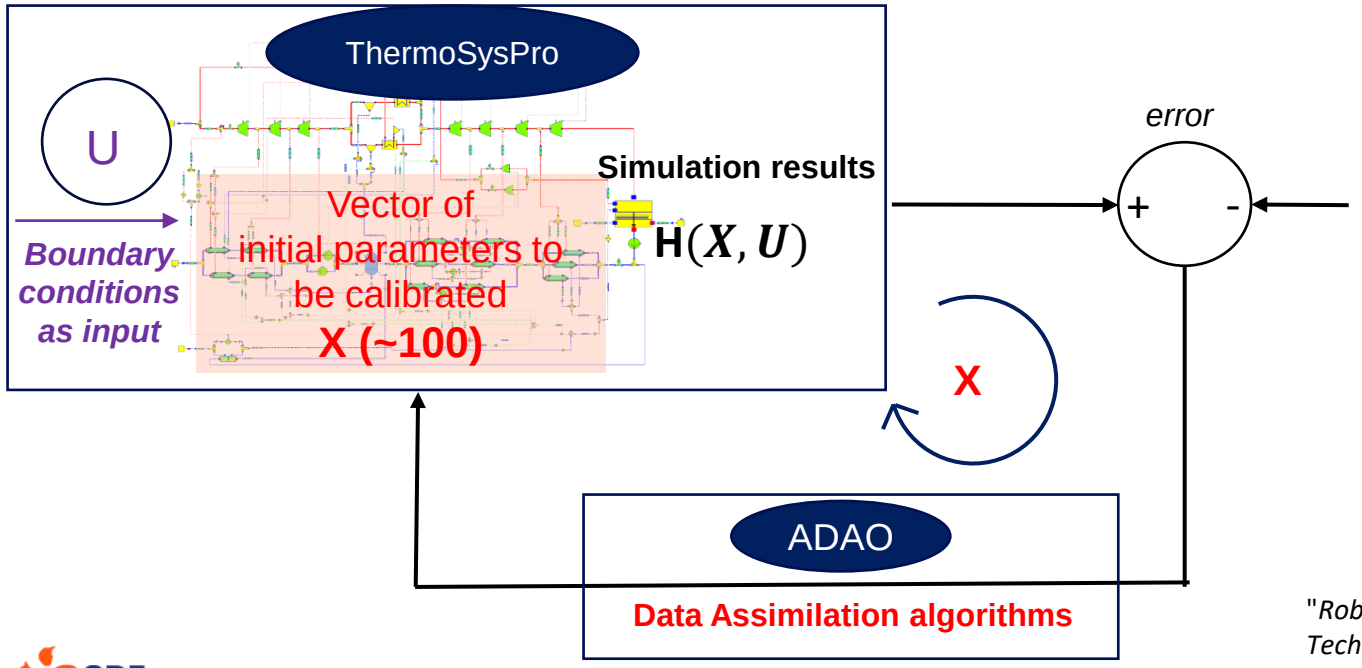
1. Framework for our industrial application

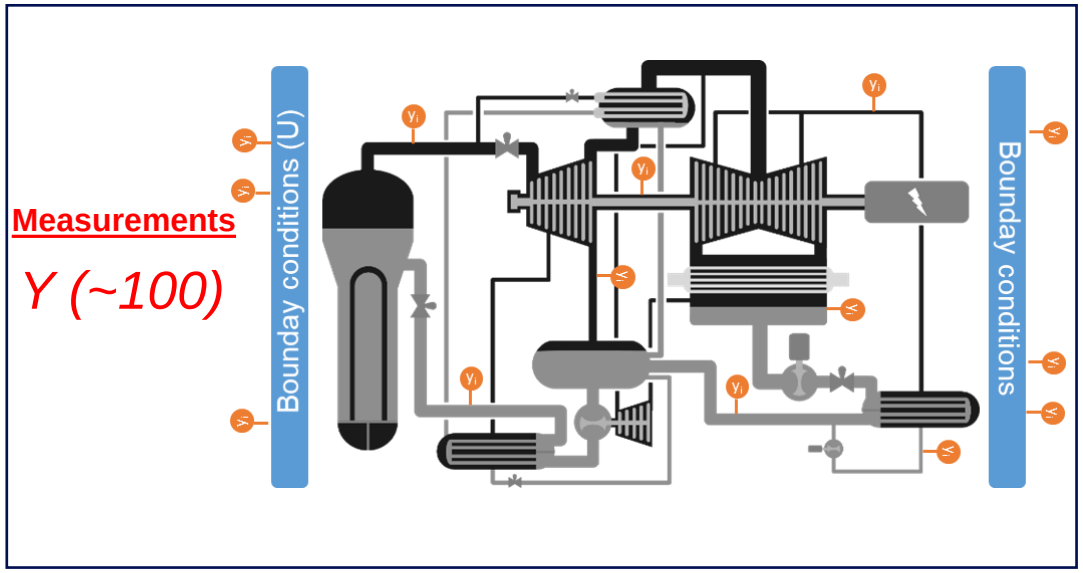
==> *Specialized view*



1. Industrial case: SCORE

- **Large industrial case**, with more than 100 parameters to be calibrated = simulation
- **Measurements or targets values** coming from real powerplant = observations
- Data assimilation used to **combine simulation and observations**, to **identify reliable parameters**, to **quality the model** and **reduce errors**, and to **diagnose model mismatch**





"*Robust Calibration of Complex ThermoSysPro Models using Data Assimilation Techniques: Application on the Secondary System of a Pressurized Water Reactor*", L. Corona Mesa-Moles et al., Proceedings of the 13th International Modelica Conference, Regensburg, Germany, March 4–6, 2019 DOI:10.3384/ecp19157553

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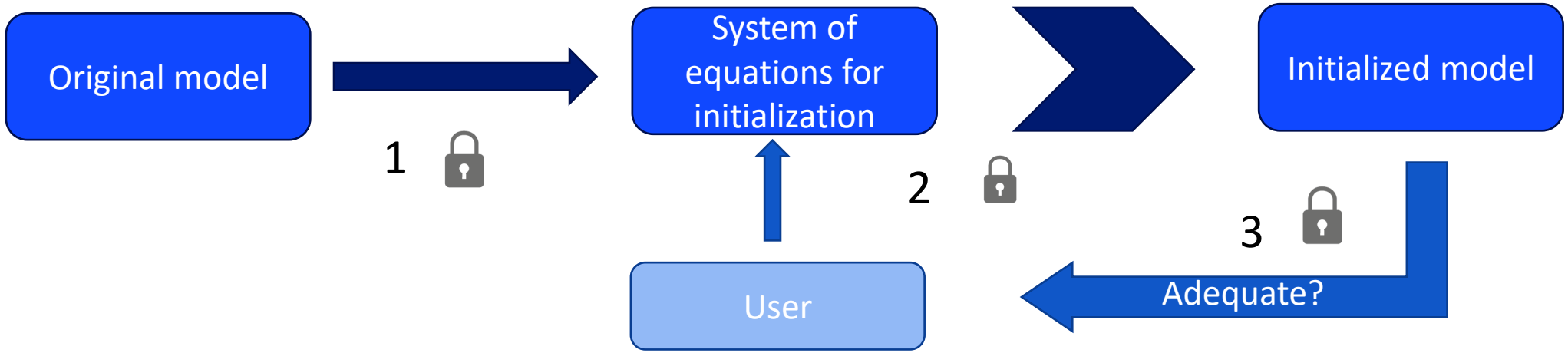
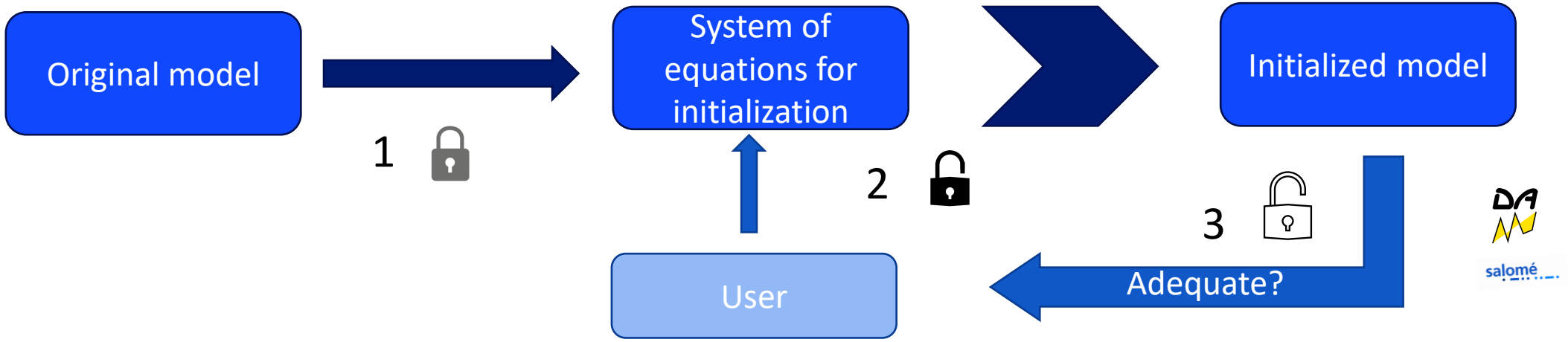
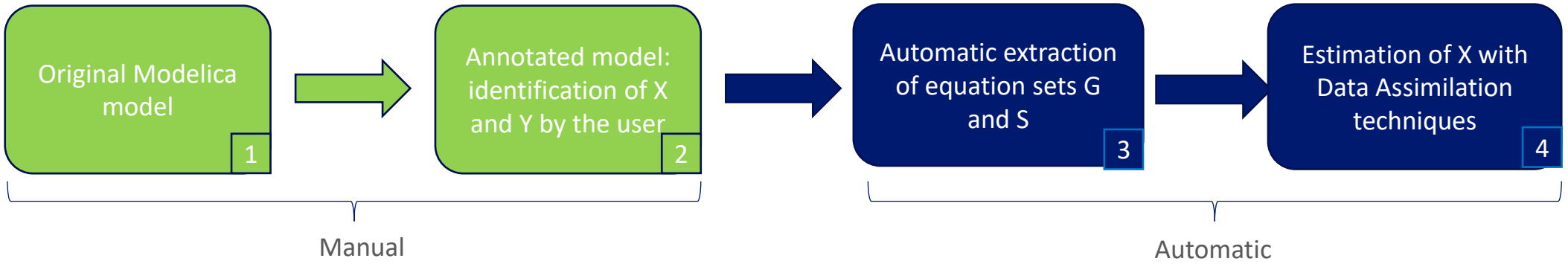
Further developments

Towards a methodological process in Modelica tools



Towards a methodological process in Modelica tools





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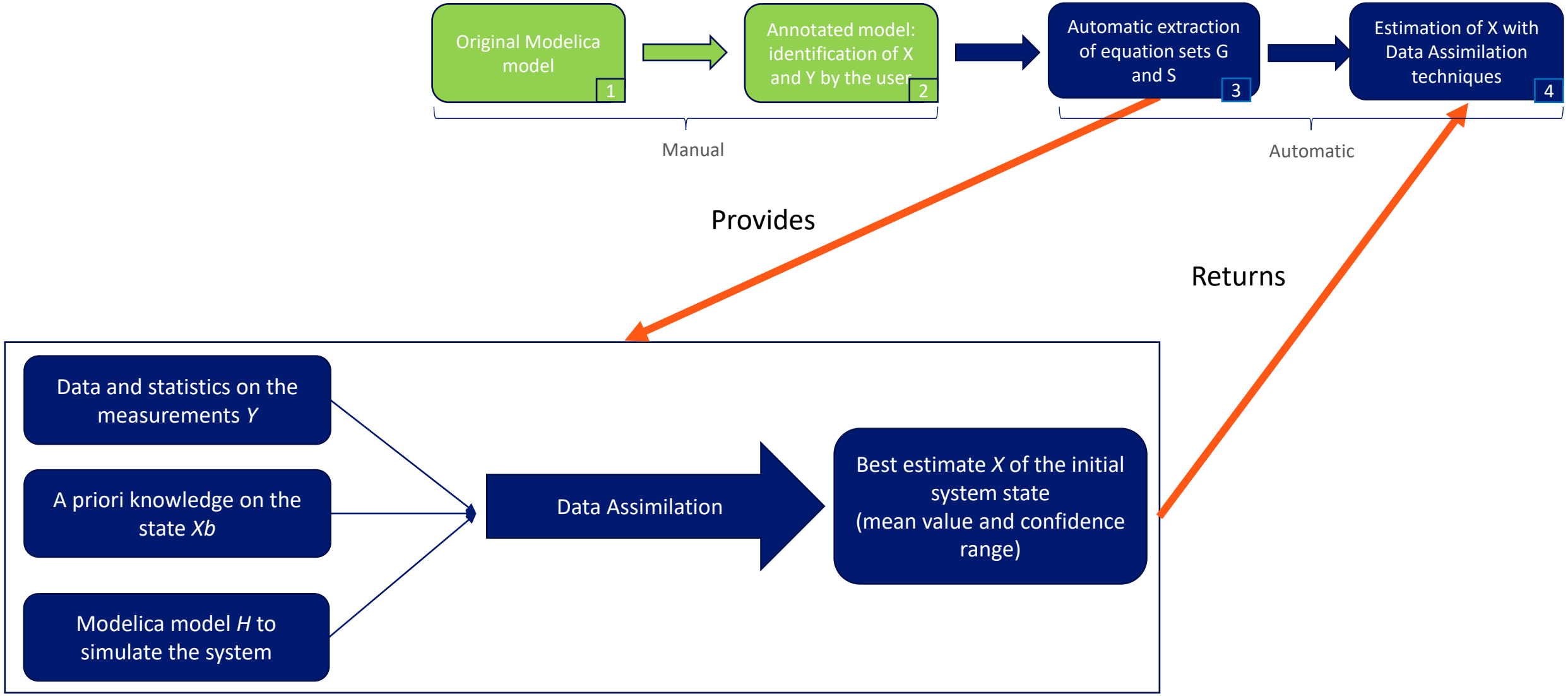


Experimentation with Modelica tools

➡ Evolutions in the frame of the **Modeliscale project**

https://www.3ds.com/modeliscale

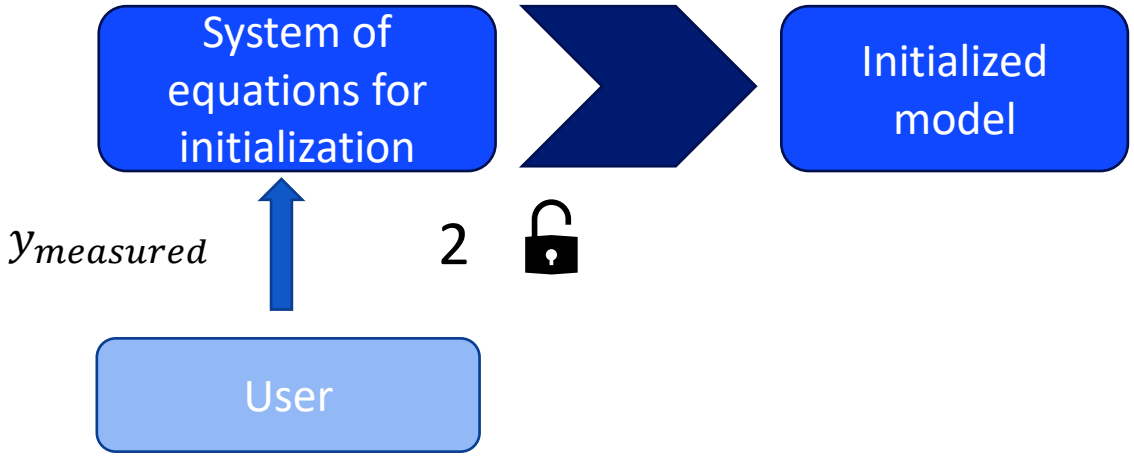
- Development of a new equation-based method for parameter and state estimation of Modelica models
- Successful prototype implementation in Dymola 2022 and 3DEXPERIENCE 2022x
- The prototype works in simple examples, but further developments are necessary to use this approach with complex models

➡ Similarities with the practical implementation of **Data Reconciliation in OpenModelica**

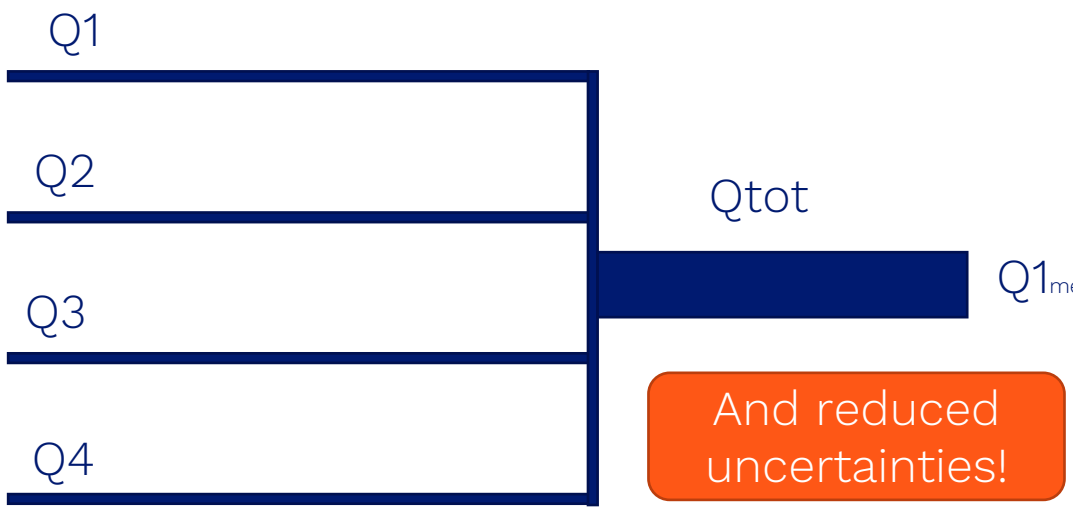
https://openmodelica.org/doc/OpenModelicaUsersGuide/latest/dataReconciliation.html

- Annotation and identification the variables of interest manually done by the user
- Information about the variables of interest provided as a file input (measurement and correlation matrix)
- Automatic extraction the equations of interest

Data Reconciliation and model intialization



Improve the input data quality based on **fundamental physical laws** such as mass, momentum and energy balance equations



Physically: Q1 + Q2 + Q3 + Q4 = Qtot

But measurements give :

$Q1_{measured} + Q2_{measured} + Q3_{measured} + Q4_{measured} \neq Qtot_{measured}$

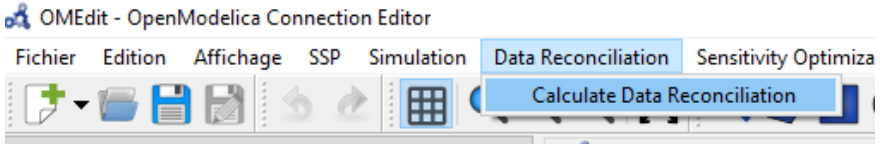
And reduced uncertainties!

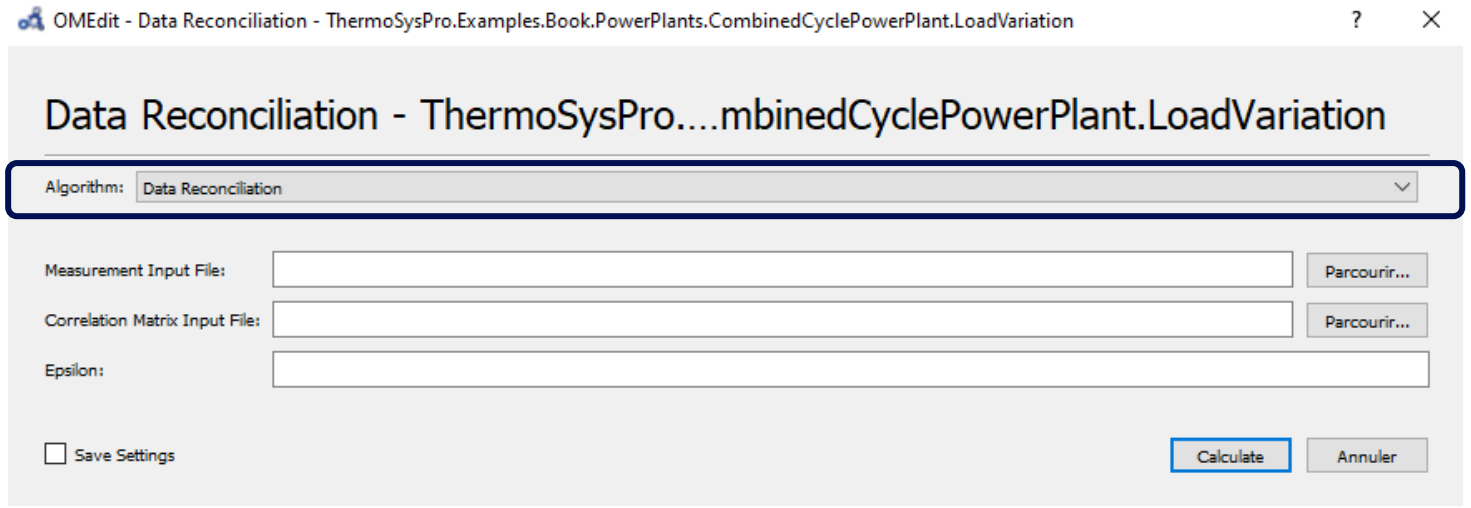
Data Reconciliation gives:

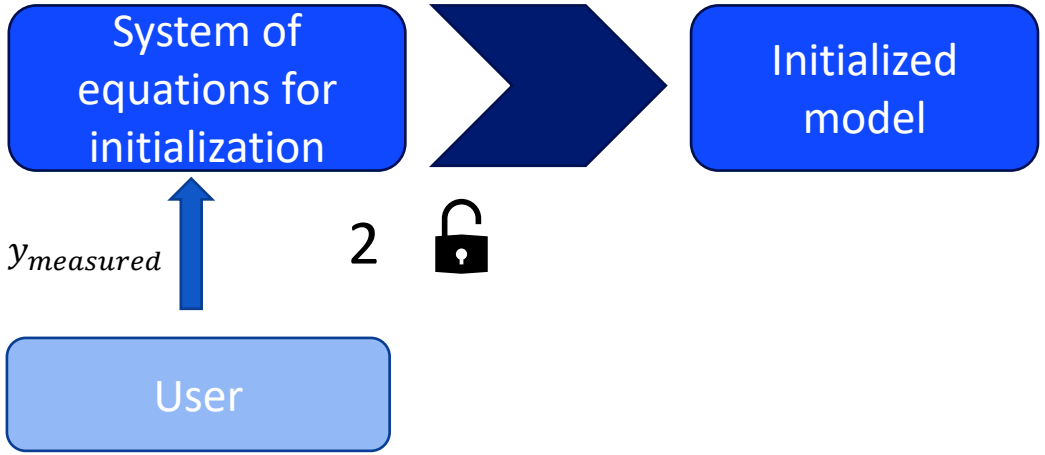
$Q1_{rec} + Q2_{rec} + Q3_{rec} + Q4_{rec} = Qtot_{rec}$

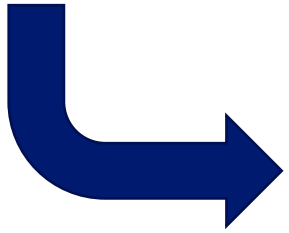
Data Reconciliation and model intialization

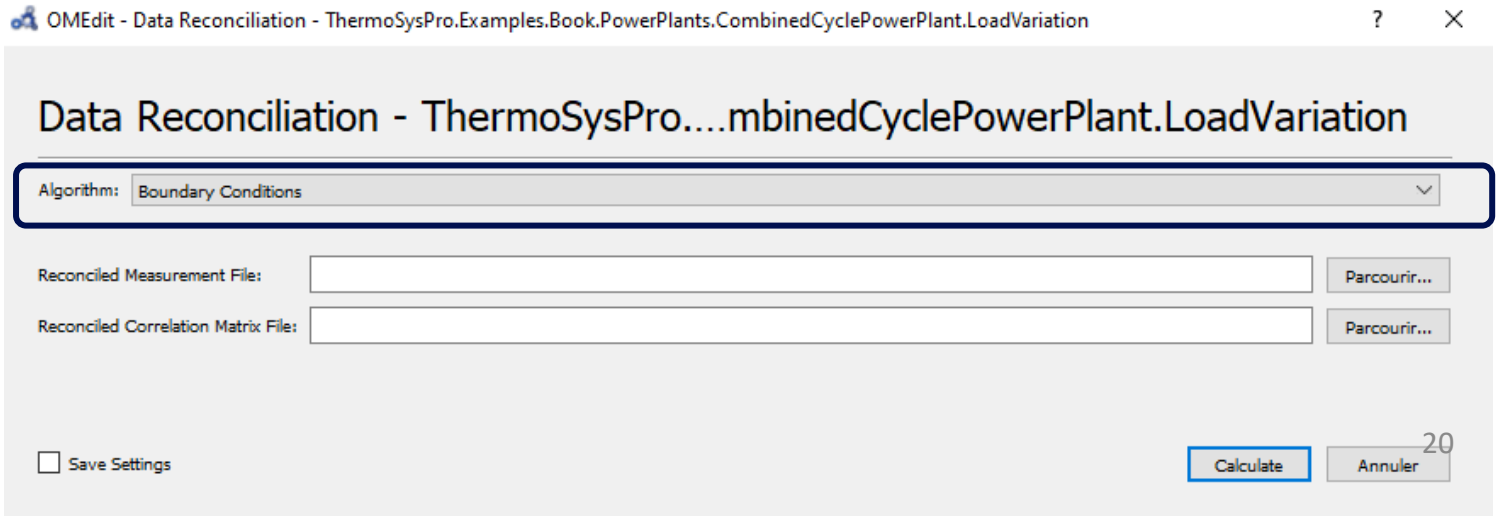
OpenModelica











Hightlights

- Initialization is a real difficulty → Robust initialization

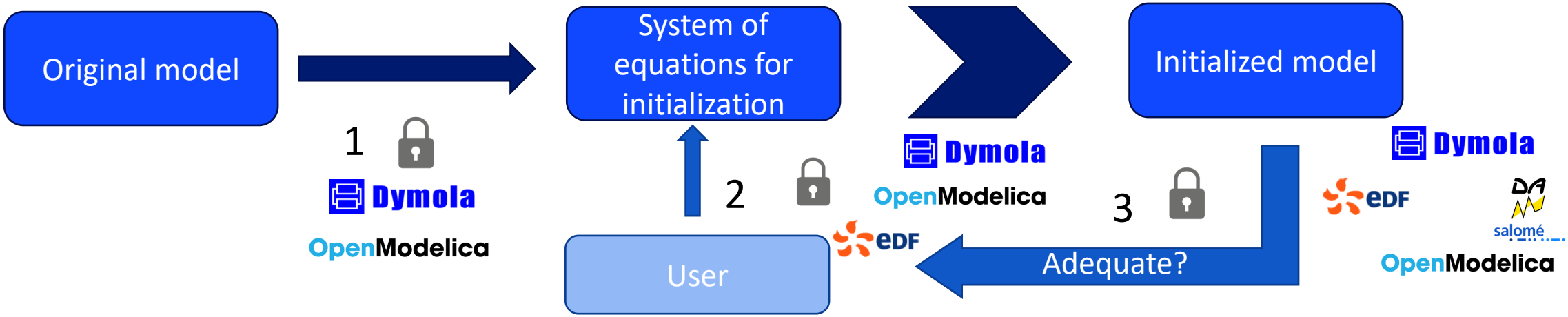
- Proposal of a way to help users with data assimilation

- Potential integration with Modelica tools demonstrated

- Similarities with data reconciliation

- Interest in integrating these methodological tools into Modelica tools

Towards a robust initialization of Modelica models



Continue the tests on the assimilation and reconciliation techniques on large models to test already existing implementations and **potential new developments**

Explore other approaches from the user point of view : use of simplified models to facilitate the initialization of more complex models, step by step model development, use of sub-models, metamodels, etc.

References

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