

# MODELING FOR SUSTAINABILITY

## *Or How to Make Smart CPS Smarter?*

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WORKSHOP MODELS@RUNTIME @ MODELS, OCTOBER, 2018

*An earlier version of this talk is available at <http://goo.gl/ksGq4N>*

**BENOIT COMBEMALE**  
PROFESSOR, UNIV. TOULOUSE & INRIA, FRANCE

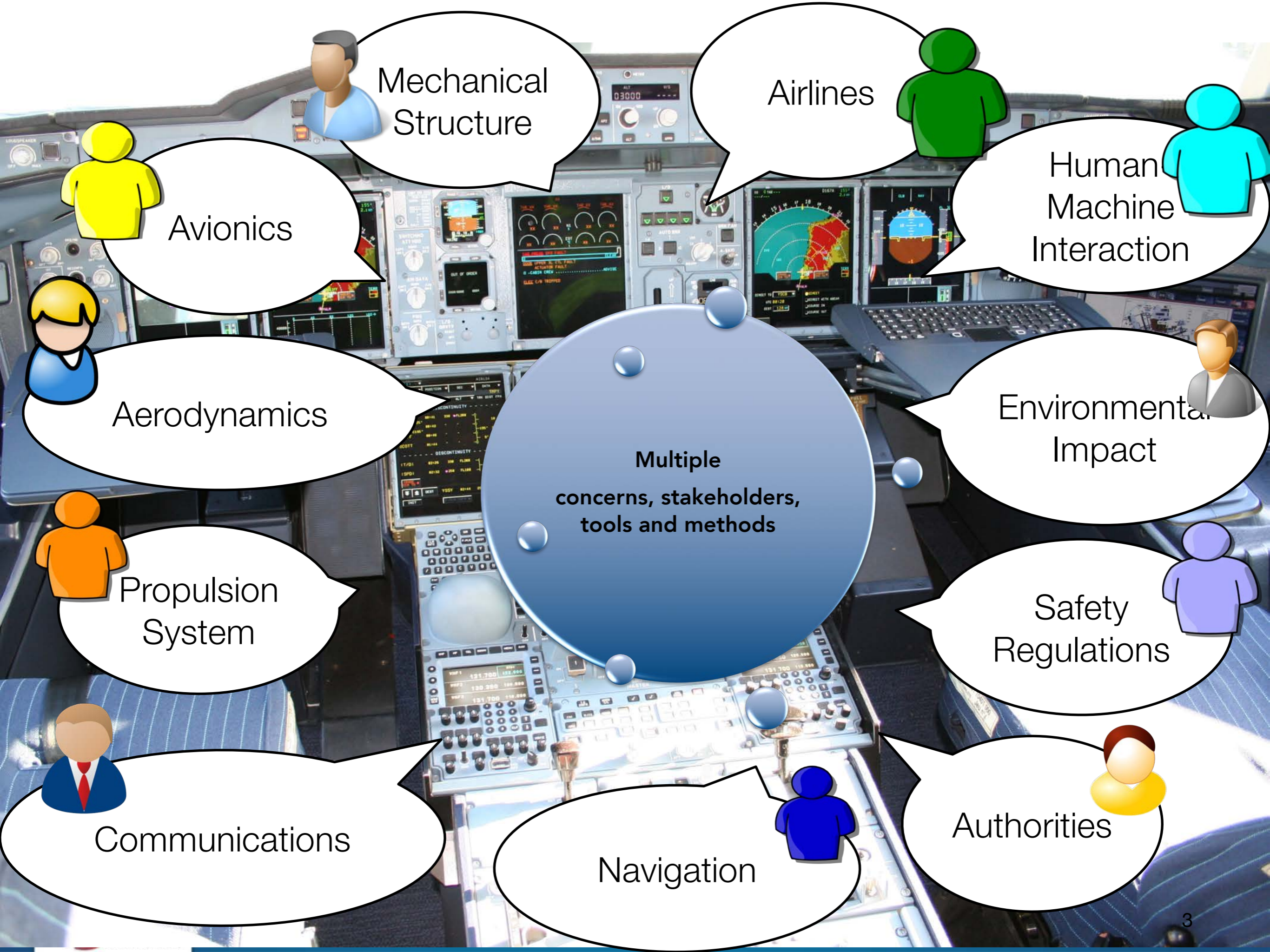
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# Complex Software-Intensive Systems



- ▶ Multi-engineering approach
- ▶ Domain-specific modeling
- ▶ High variability and customization
- ▶ Software as integration layer
- ▶ Openness and dynamicity



Mechanical Structure

Airlines

Human Machine Interaction

Avionics

Aerodynamics

Environmental Impact

Multiple concerns, stakeholders, tools and methods

Safety Regulations

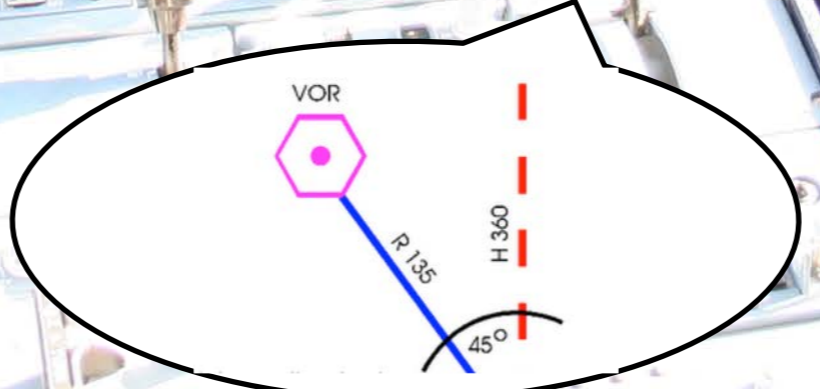
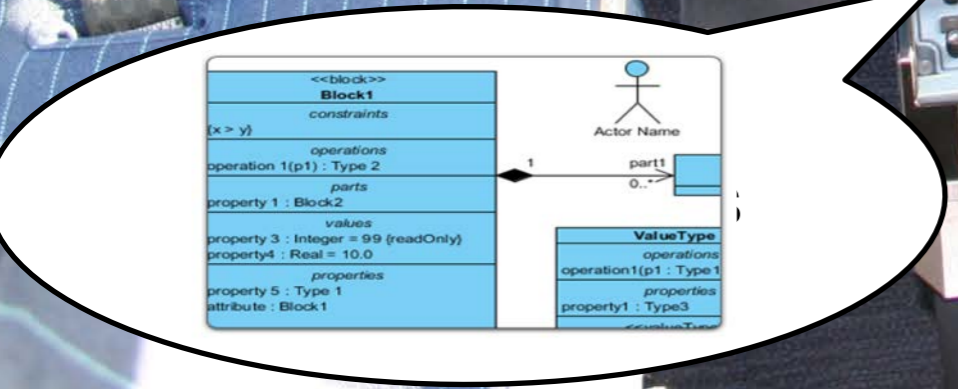
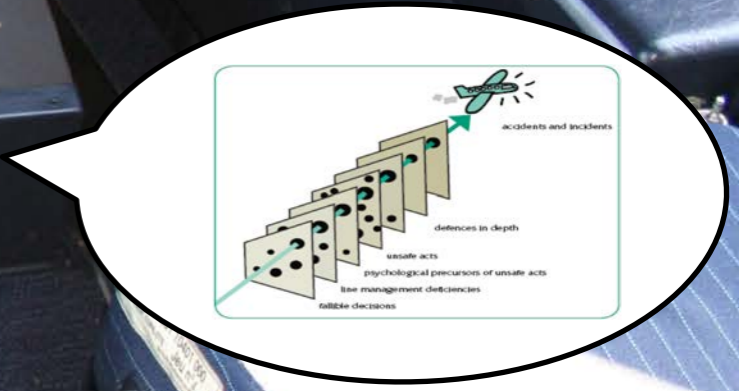
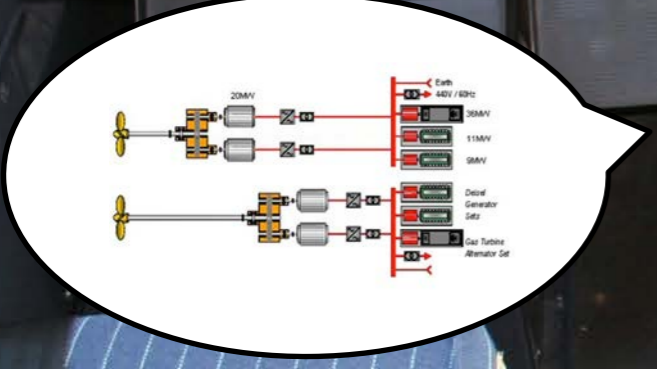
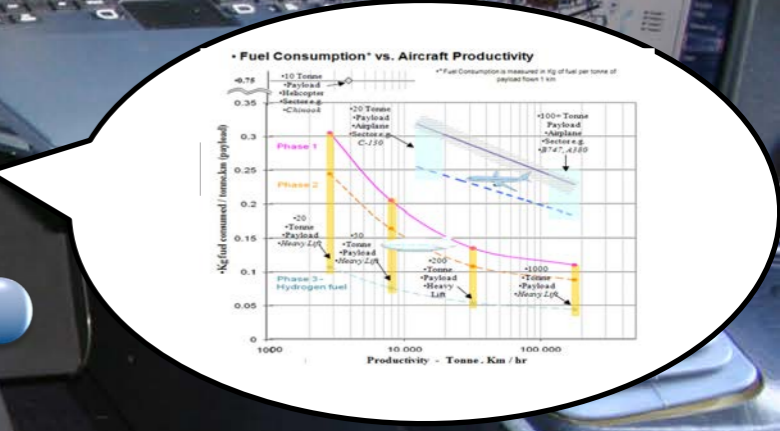
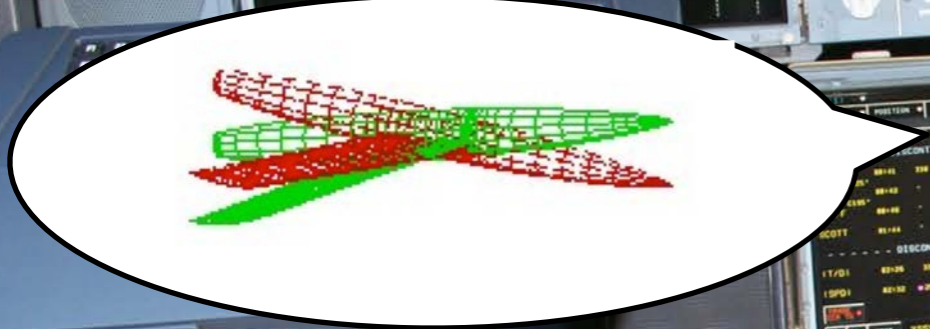
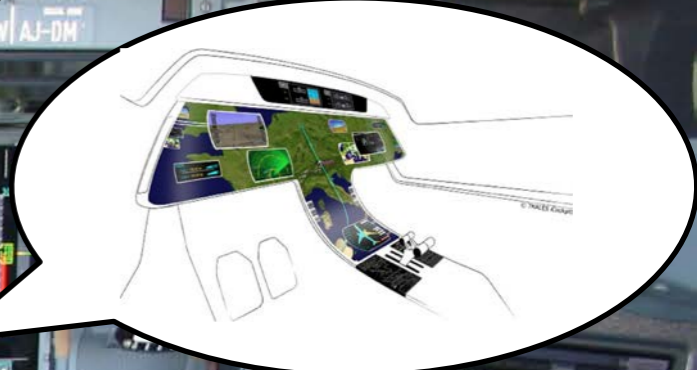
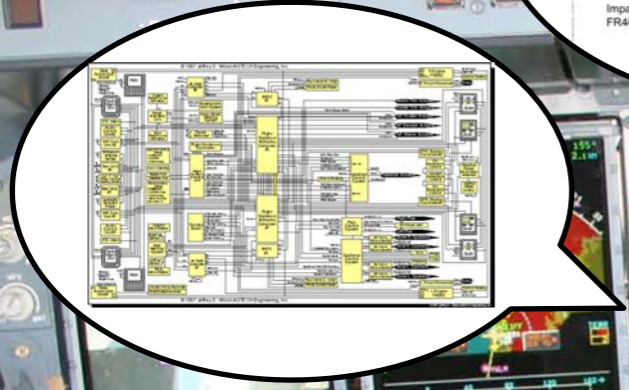
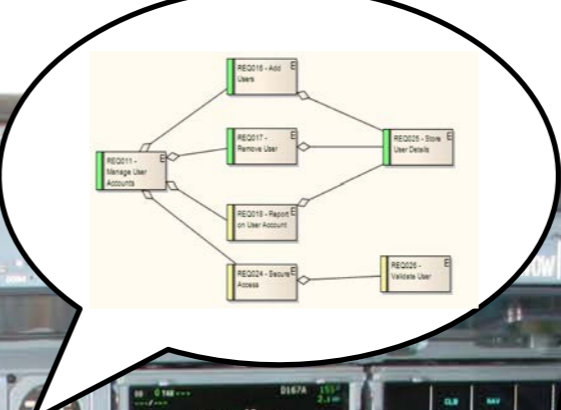
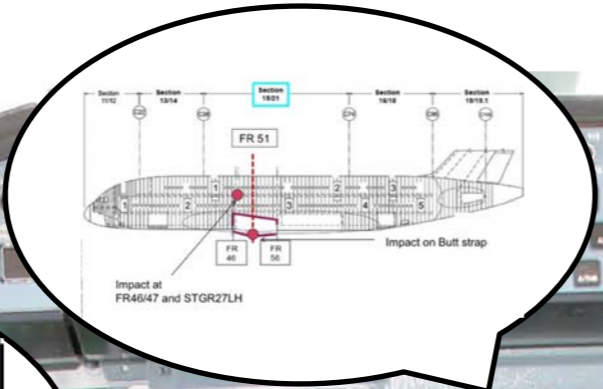
Propulsion System

Authorities

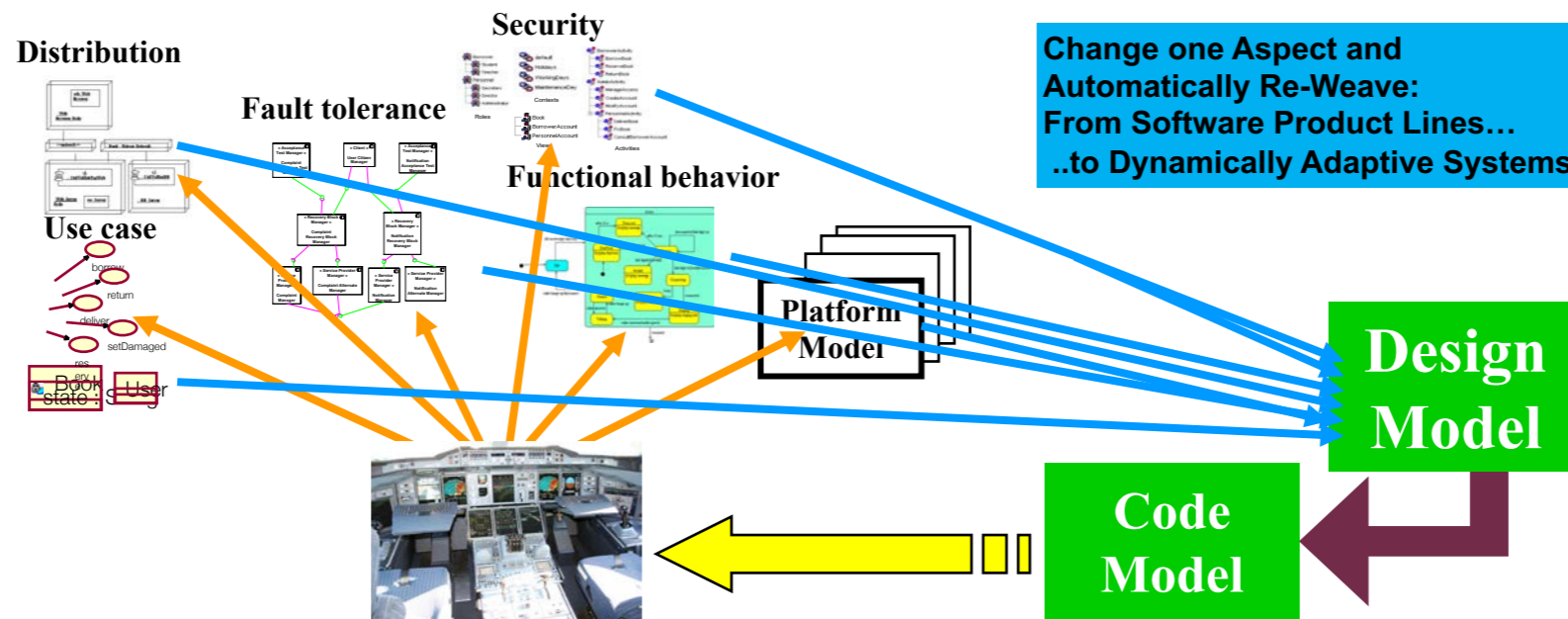
Communications

Navigation

# Heterogeneous Modeling



# Model-Driven Engineering



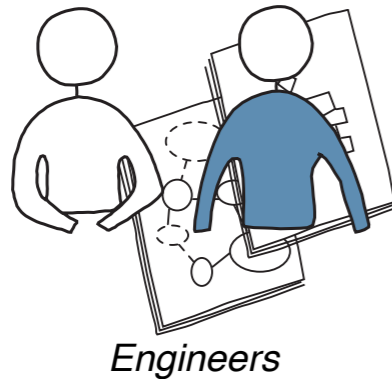
*"Perhaps surprisingly, the majority of MDE examples in our study followed domain-specific modeling paradigms"*

J. Whittle, J. Hutchinson, and M. Rouncefield, "The State of Practice in Model-Driven Engineering," IEEE Software, vol. 31, no. 3, 2014, pp. 79–85.

# From Software Systems

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**System Models**

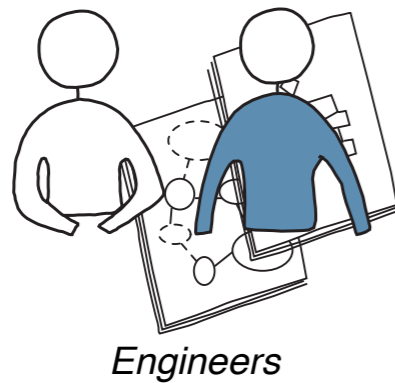


Software

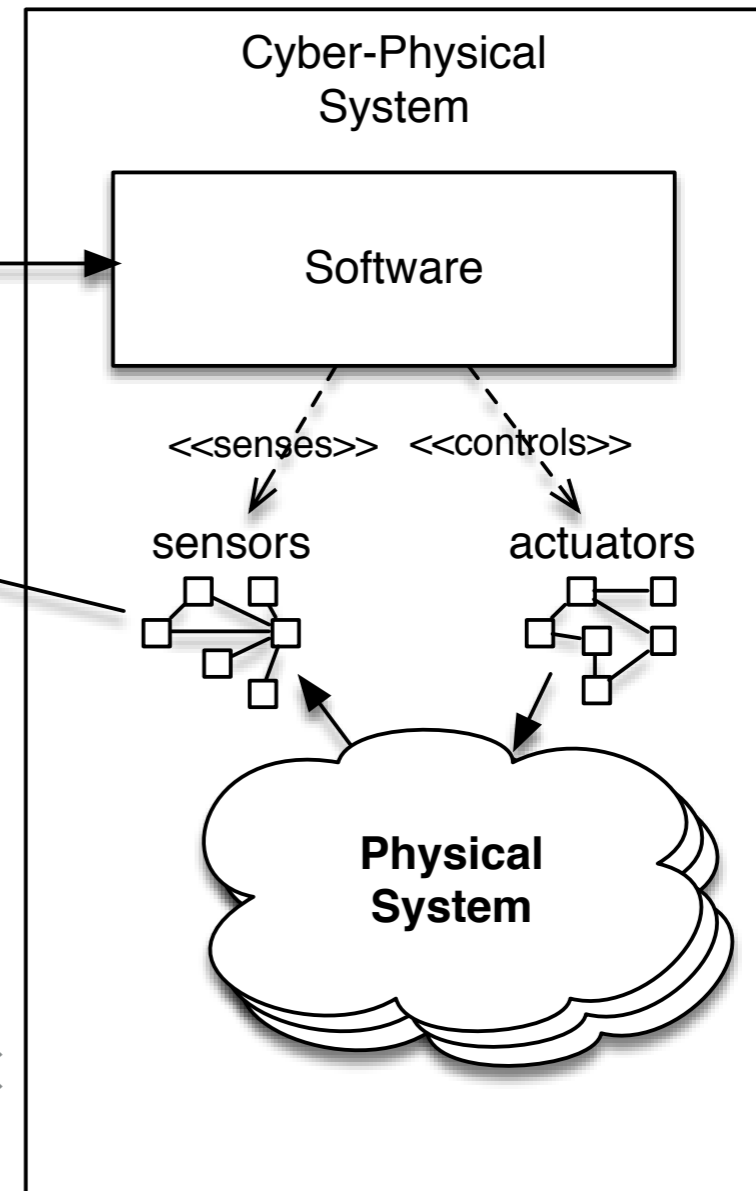
- ▶ software design models for functional and non-functional properties

# To Cyber-Physical Systems

## System Models

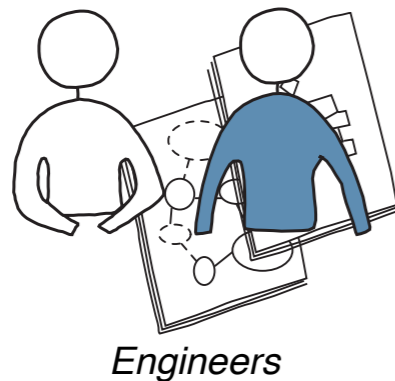


- ▶ multi-engineering design models for global system properties
- ▶ models @ runtime (i.e., included into the control loop) for dynamic adaptations

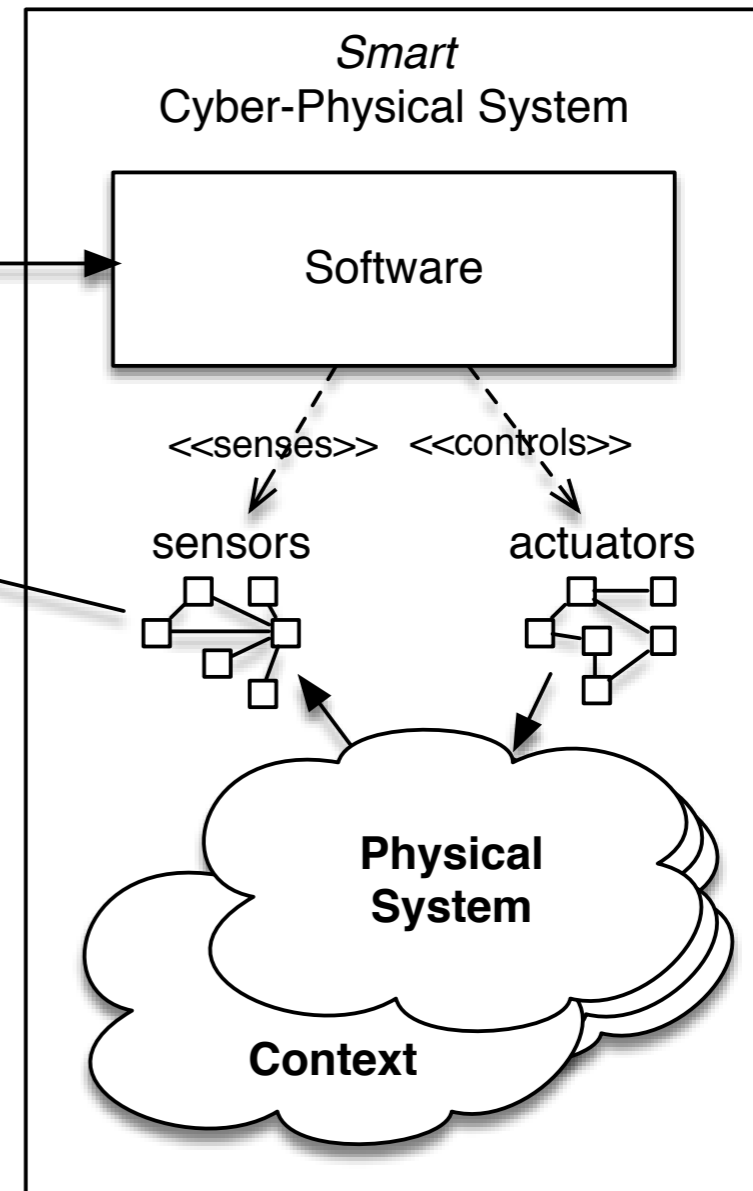


# To Smart Cyber-Physical Systems

## System Models



- ▶ **analysis models** (incl. large-scale simulation, constraint solver) of the surrounding context related to global phenomena (e.g. physical, economical, and social laws)
- ▶ **predictive models** (predictive techniques from AI, machine learning, SBSE, fuzzy logic)
- ▶ **user models** (incl., general public/community preferences) and **regulations** (political laws)

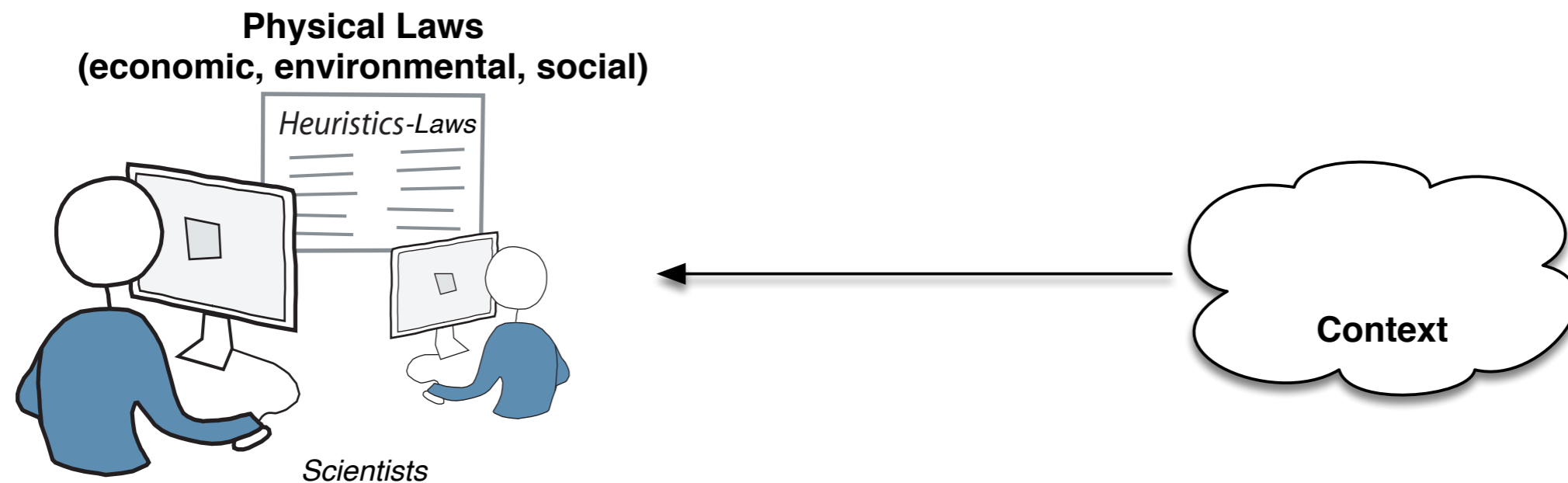




# What about Scientific Modeling?

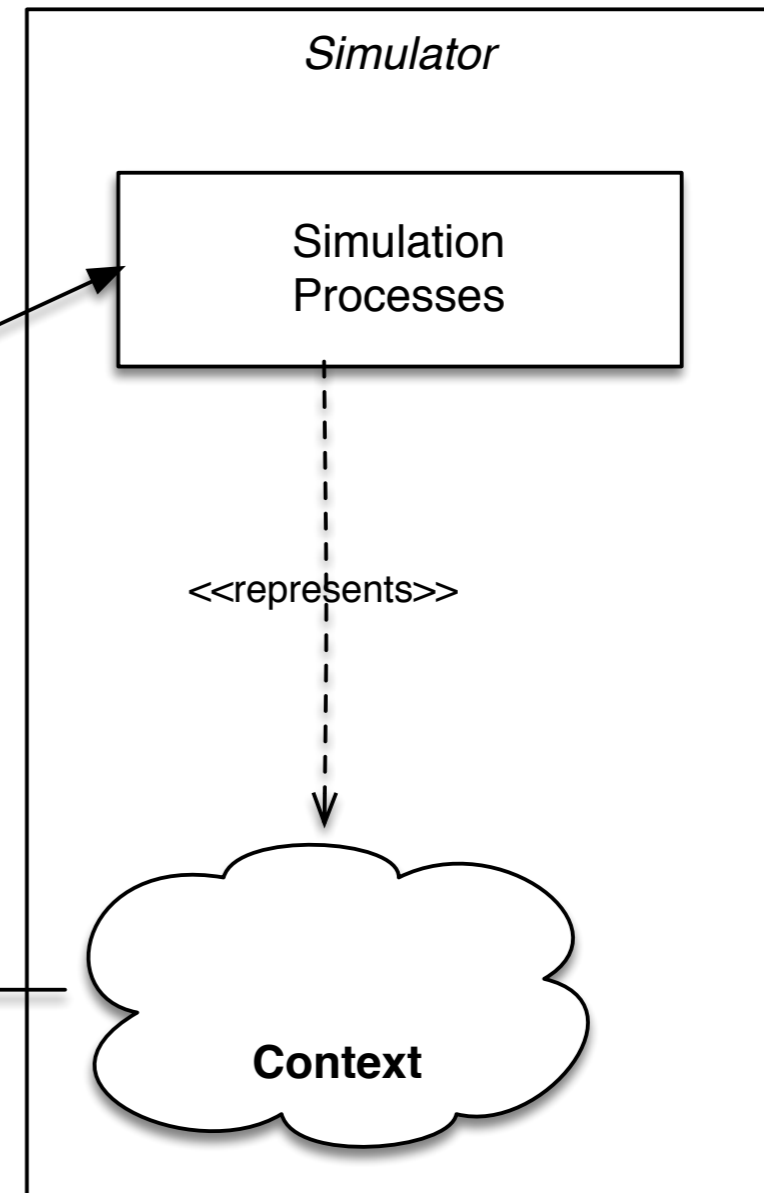
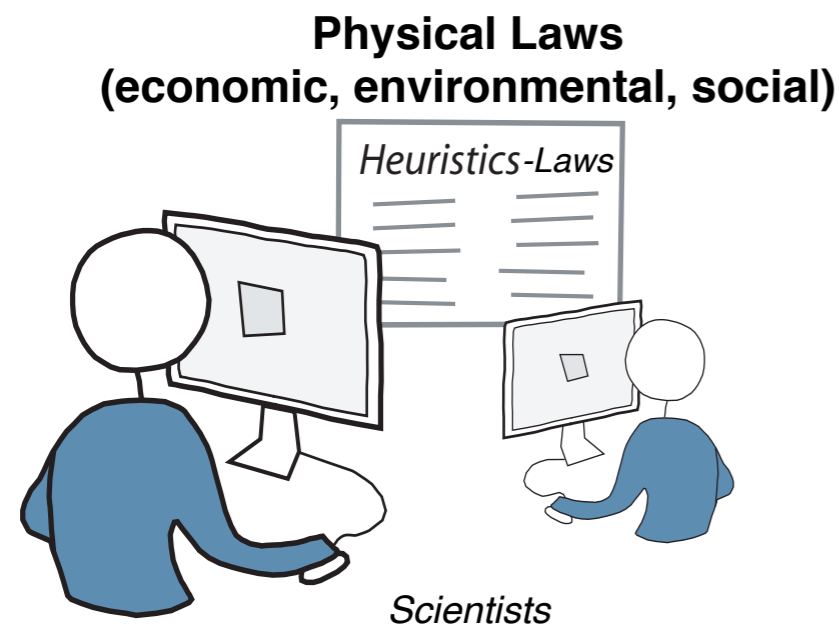
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- ▶ Models (computational and data-intensive sciences) for analyzing and understanding physical phenomena



# What about Scientific Modeling?

- ▶ **Simulators** for tradeoff analysis, what-if scenarios, analysis of alternatives and adaptations to environmental changes, etc.



# Towards Unifying Modeling Foundations

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- ▶ Convergence of *engineering* and *scientific* models
  - ▶ Prescriptive requires descriptive models
  - ▶ Descriptive requires prescriptive models
- ▶ Grand Challenge: a modeling framework to support the integration of data from sensors, open data, laws, regulations, scientific models (computational and data-intensive sciences), engineering models and preferences.
- ▶ Domain-specific languages (DSLs) for socio-technical coordination
  - ▶ to engage engineers, scientists, decision makers, communities and the general public
  - ▶ to integrate analysis/predictive/user models into the control loop of smart CPS

# Sustainability Systems

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- ▶ Sustainability systems are smart-CPS managing resource production, transport and consumption for the sake of sustainability
  - ▶ Ex: smart grids, smart city/home/farming, etc.
- ▶ Sustainability systems
  - ▶ must balance trade-offs between the social, technological, economic, and environmental pillars of sustainability
  - ▶ involve complex decision-making with heterogeneous analysis models, and large volumes of disparate data varying in temporal scale and modality

# MDE for Sustainability Systems

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- ▶ Scientific models are used to understand sustainability concerns and evaluate alternatives (what-if/for scenarios)
- ▶ Engineering models are used to support the development and runtime adaptation of sustainability systems.

**How to integrate engineering and scientific models in a synergistic fashion to support informed decisions, broader engagement, and dynamic adaptation in sustainability systems?**

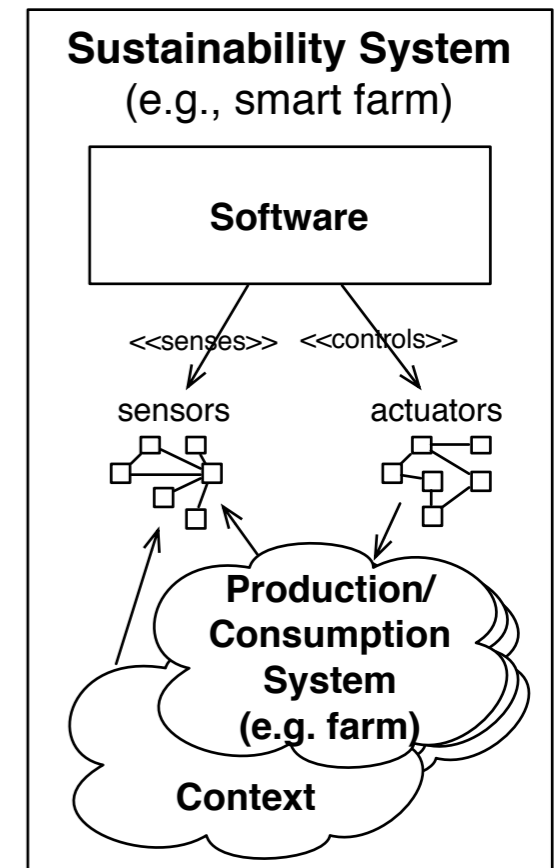
Modeling for Sustainability

B. Combemale, B. Cheng, A. Moreira, J.-M. Bruel, J. Gray

In *MISE @ ICSE*, 2016

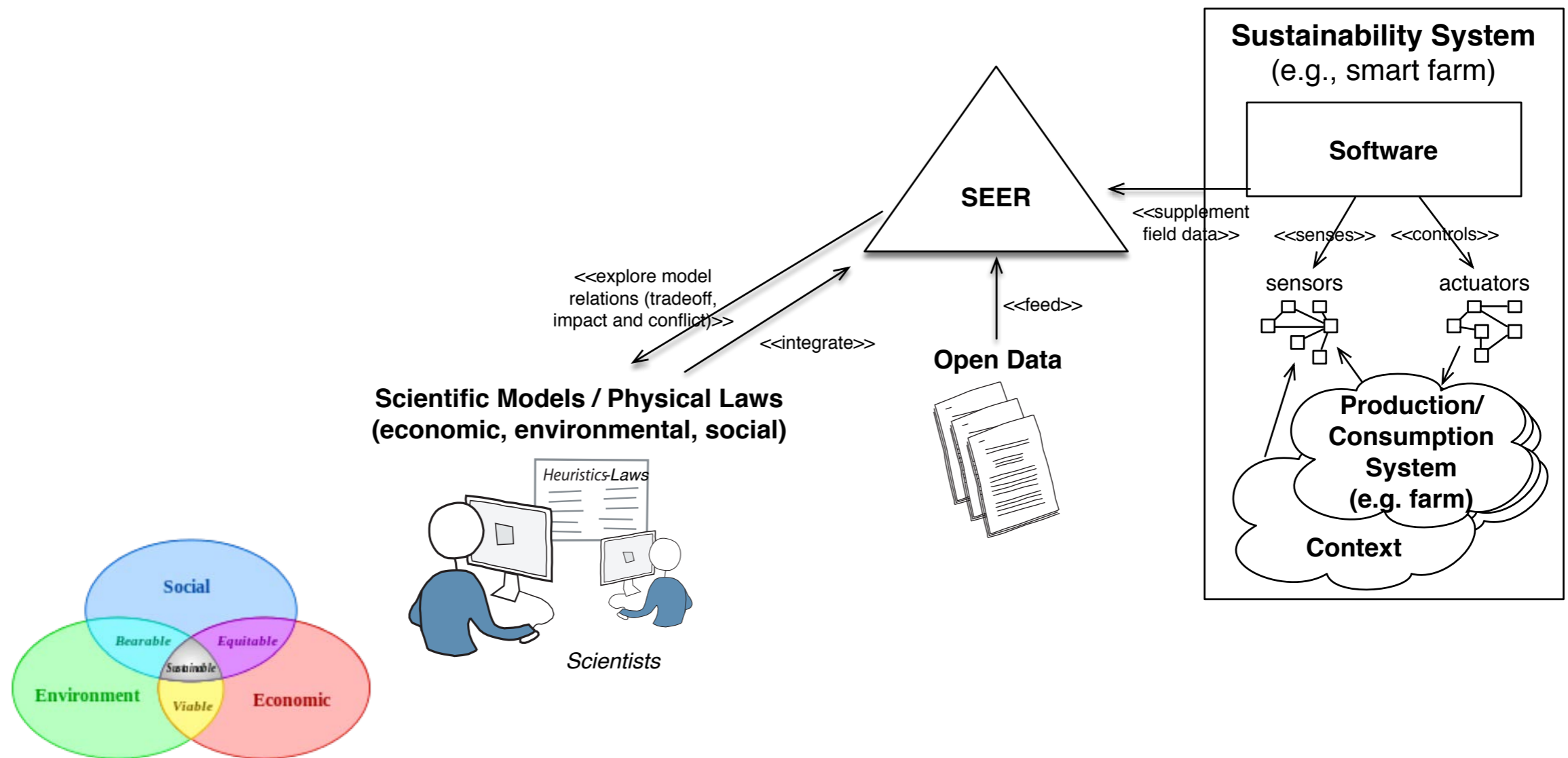
# The Sustainability Evaluation ExperienceR (SEER)

## ▶ Smart Cyber-Physical Systems



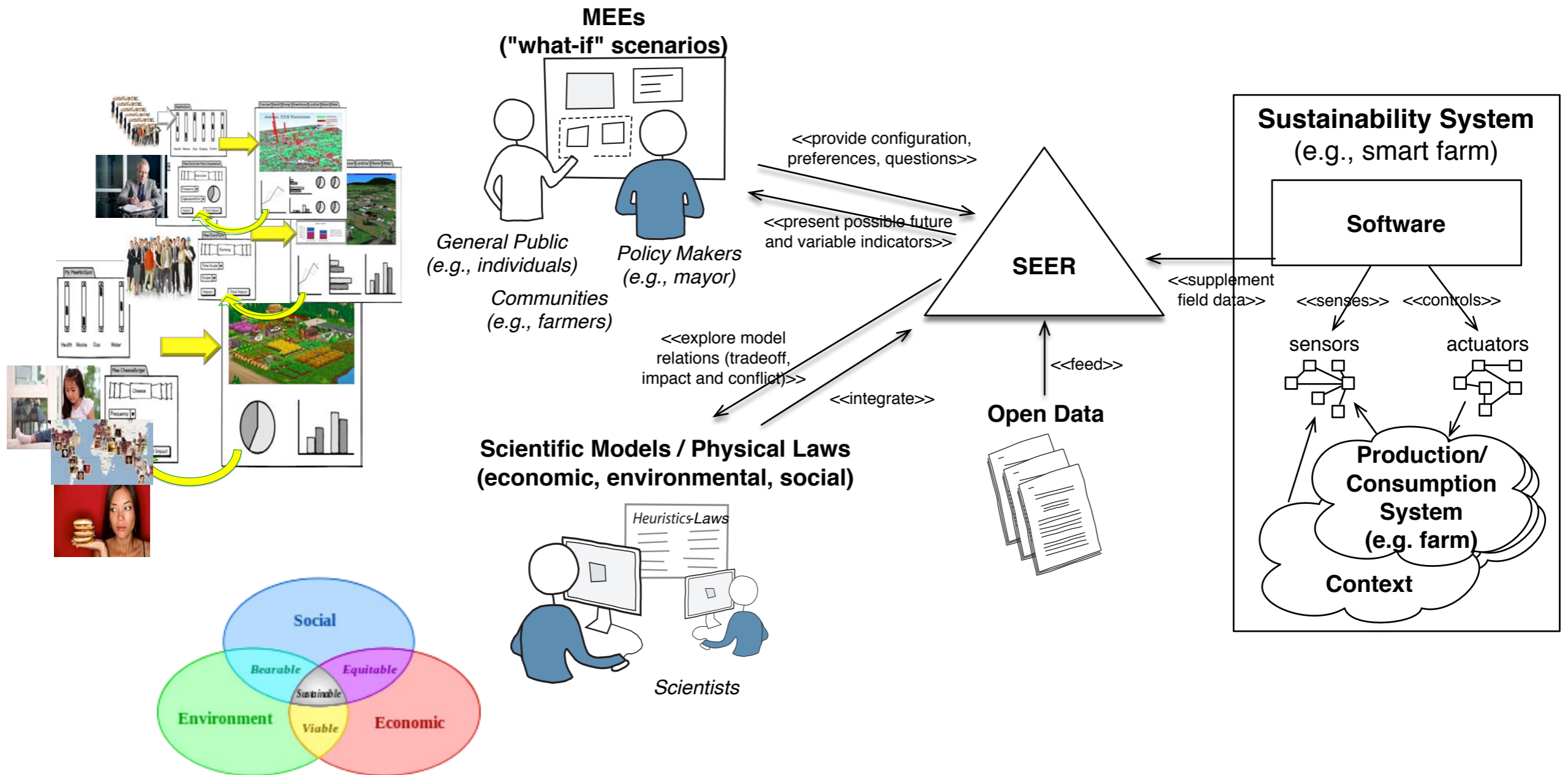
# The Sustainability Evaluation ExperienceR (SEER)

- ▶ Based on informed decisions
  - ▶ with environmental, social and economic laws
  - ▶ with open data



# The Sustainability Evaluation ExperienceR (SEER)

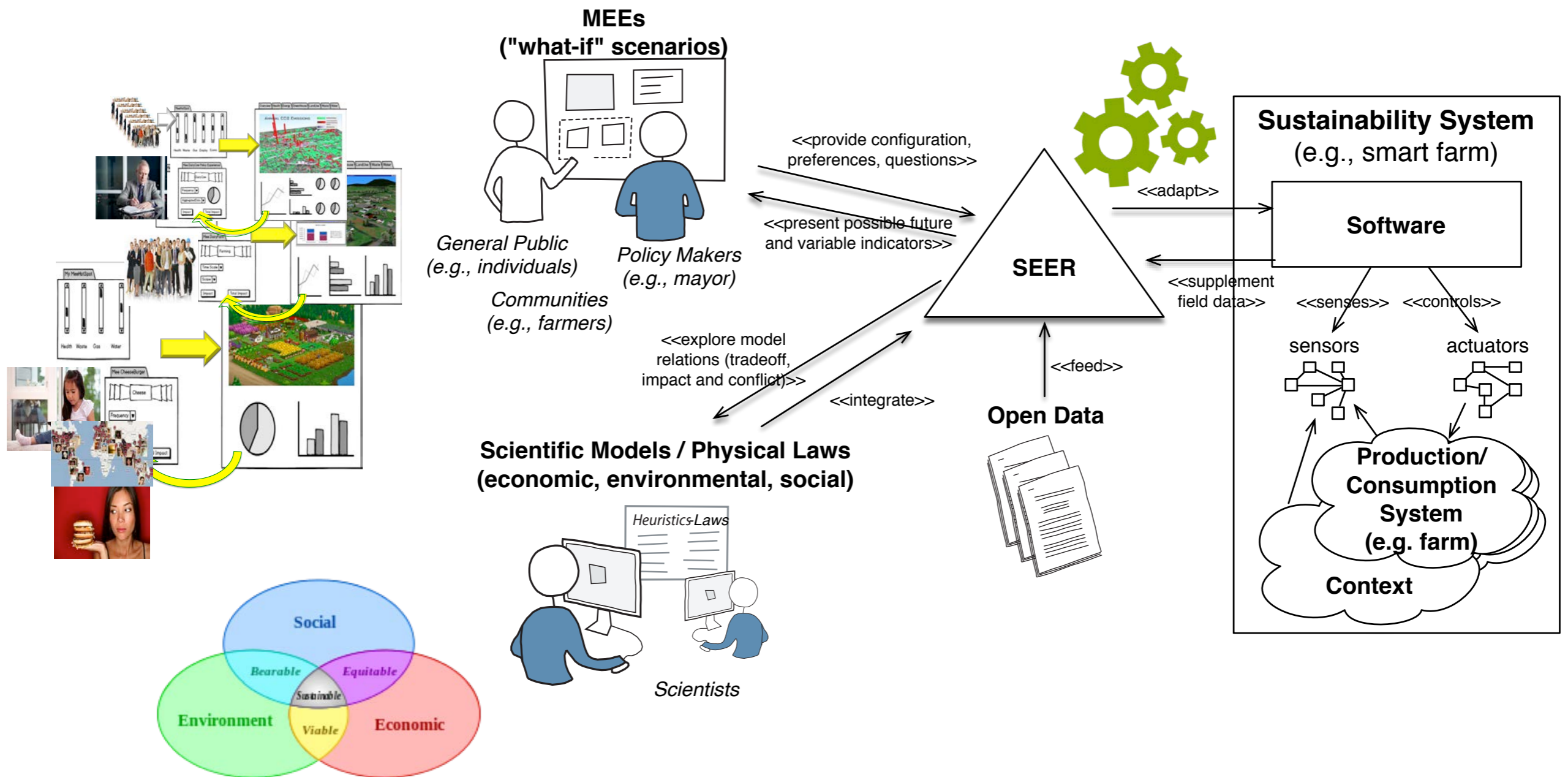
- ▶ Providing a broader engagement
  - ▶ with "what-if" scenarios for general public and policy makers





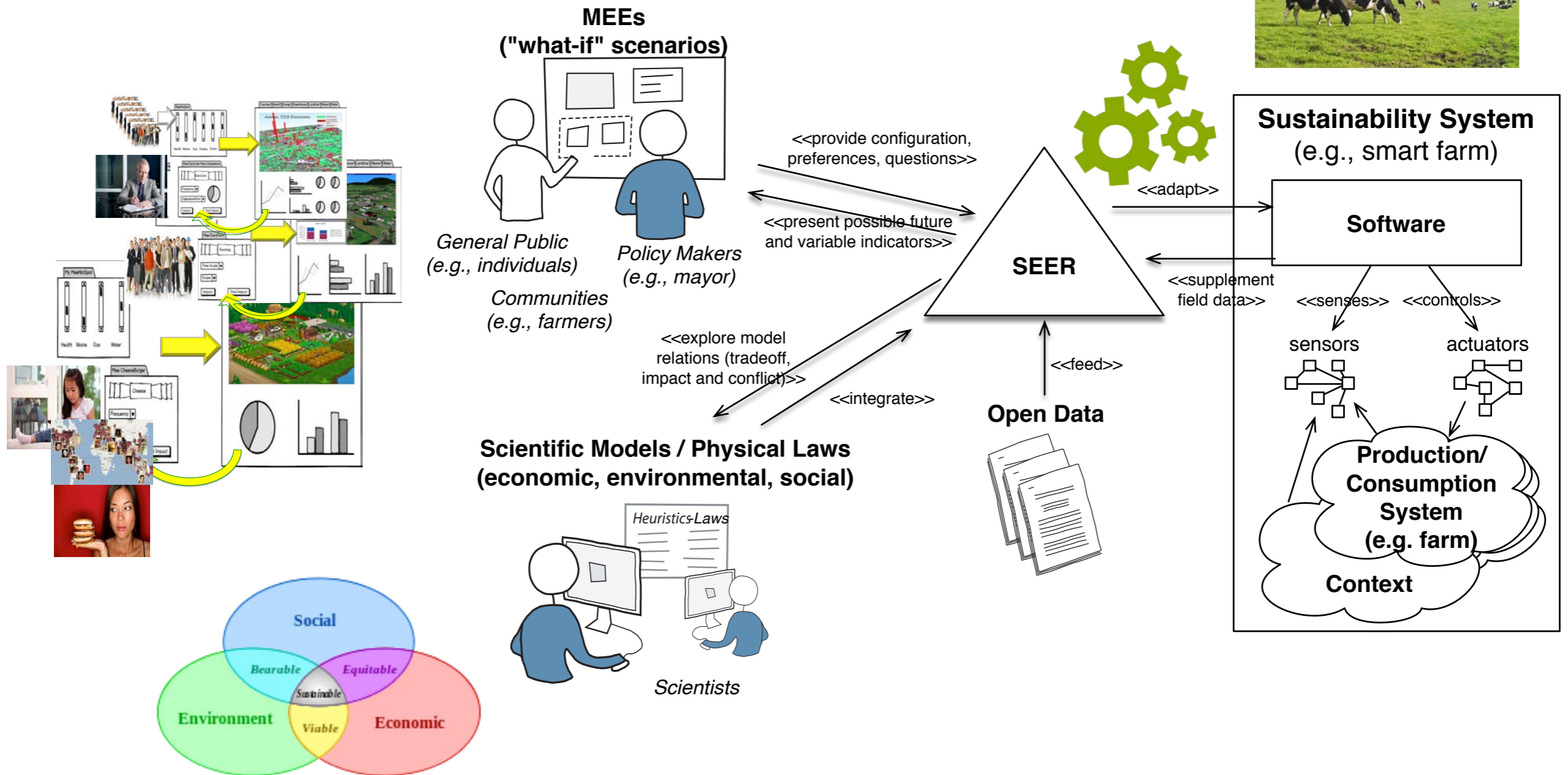
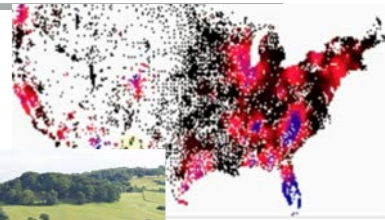
# The Sustainability Evaluation ExperienceR (SEER)

- ▶ Supporting automatic adaptation
  - ▶ for dynamically adaptable systems



# The Sustainability Evaluation ExperienceR (SEER)

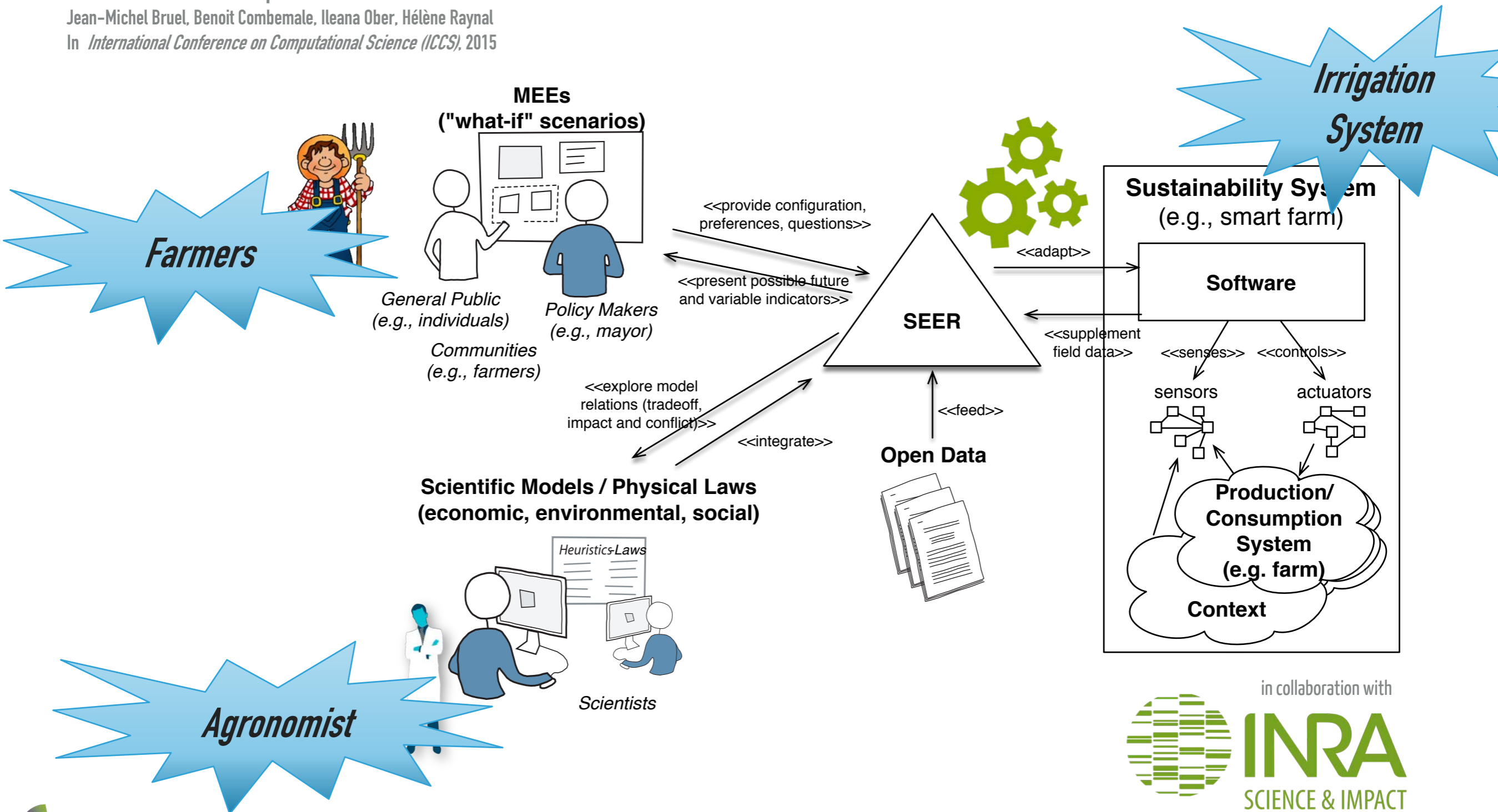
- ▶ Application to health, farming system, smart grid...



# The Sustainability Evaluation ExperienceR (SEER)

MDE in Practice for Computational Science

Jean-Michel Bruel, Benoit Combemale, Ileana Ober, H el ene Raynal  
In *International Conference on Computational Science (ICCS)*, 2015



# FARMING SYSTEM MODELING

Modeling - MyExploitation/analysis.scientific - Eclipse Platform

**Model Explorer**

- MyExploitation [farmingmodeling master]
  - Project Dependencies
  - src-gen
  - analysis.scientific
  - climate.simulation
  - cultures.activities
  - John.exploitation
  - representations.aird
  - schedule.simulation

**Outline** \*Schedule

- NW of Exploitation 4 fields
  - corn LABOUR scheduled on 13/jan
  - corn SEMIS scheduled on 31/mar
  - corn IRRIGATION scheduled on 4/aug
  - corn FERTILISATION scheduled on 5/may
  - corn RECOLTE scheduled on 1/sept
- 2 fields
  - corn LABOUR scheduled on 1/jan
  - corn SEMIS scheduled on 15/mar
  - corn IRRIGATION scheduled on 15/jun
  - corn FERTILISATION scheduled on 27/may
  - corn RECOLTE scheduled on 21/sept

**cultures.activities**

```

culture corn {
    activity LABOUR from 1 jan to 28 feb
        using 1 Tractor and 1 People

    activity SEMIS from 15 mar to 15 apr [
        after LABOUR && no rain since 3 days && tempe
    ] using 1 Tractor and 2 People

    activity IRRIGATION weekly from 15 jun to 15 aug
        after SEMIS
    ] using 1 Tractor and 1 People

    activity FERTILISATION from 15 mar to 15 jun [
        after SEMIS is done since 30 days &&
        no rain since 1 days
    ] using 1 Tractor and 1 People

    activity RECOLTE from 1 sept to 30 sept [
        grain is "mature" &&
        after SEMIS
    ] using 1 Tractor and 2 People
}
        
```

**\*corntasks dependencies**

**\*exploitation description**

Extra Water needed : 161600m³

**\*Hydro Analysis**

Surface...	Extra Water	Rain	Hyd	Biomass	LAI
31 mar	0.0	0.0	57.0	0.00761125...	0.000
1 apr	0.0	0.0	57.5	0.01527933...	0.000
2 apr	0.0	0.0	57.5	0.01730399...	0.000
3 apr	0.0	0.0	57.5	0.02231124...	0.000
4 apr	40.0	0.0	60.5	0.02865451...	0.000
5 apr	0.0	0.0	21.5	0.03494558...	0.000
6 apr	0.0	11.0	22.0	0.03872302...	0.000
7 apr	0.0	5.0	16.5	0.04052190...	0.000
8 apr	0.0	0.0	11.5	0.04548258...	0.000
9 apr	0.0	0.0	11.5	0.04743018...	0.000
10 apr	0.0	11.5	11.5	0.05144848...	0.000
11 apr	0.0	0.5	0.0	0.05425001...	0.000
12 apr	0.0	2.5	-0.5	0.05883383...	0.000
13 apr	0.0	0.5	-3.0	0.05883383...	0.000

**\*Climate Data**

	Rain (mm)	Temperature (°C)	Ray (Joules/cm²)
apr 7	5.0	10.4	626.0
apr 8	0.0	10.4	298.0
apr 9	0.0	11.0	775.0
apr 10	11.5	11.4	293.0
apr 11	2.5	9.9	700.0
apr 12	0.5	10.7	450.0
apr 13	0.5	9.7	815.0

**analysis.scientific**

- Resource Set
  - platform:/resource/MyExploitation/analysis.scientific
    - Exploitation Analysis 60.0
      - Biomass Model 1.85
      - Biomass Model 1.85
      - Biomass Model 1.85

**Properties**

Property	Value
A	0.0065
B	0.00205
Culture	Culture wheat
Eb	1.85
Eimax	0.94
K	0.5
Lmax	6.5

<https://github.com/gemoc/farmingmodeling>

# WATER FLOOD PREDICTION

The screenshot displays a web-based workflow editor interface. On the left, a 'List of available components' panel shows 'Raw data', 'Model', 'Processing', 'Simulation', and 'Visualisation'. The main workspace shows a graph with three nodes: 'Raw data', 'Processing', and 'Visualisation', connected in a linear sequence. Below the graph, the 'Processing' node configuration is shown, including a 'Name' field, a 'Data available from the previous nodes' section (showing 'No data from previous nodes'), and a 'Code' section with the following code:

```
1 temperatures = [  
2   [7, 6.9, 9.5, 14.5, 18.4, 21.5, 25.2, 26.5, 23.3, 18.3, 13.9, 9.6],  
3   [3.9, 4.2, 5.7, 8.5, 11.9, 15.2, 17, 16.6, 14.2, 10.3, 6.6, 4.8]  
4 ]  
5  
6 months = ['Jan', 'Feb', 'Mar', 'Apr', 'May', 'Jun', 'Jul', 'Aug', 'Sep', 'Oct', 'Nov', 'Dec']  
7  
8 # Use the function below to choose the data you want to send to the next nodes.  
9 # Add each variable between the parenthesis. They will be accessible from the next nodes with  
10 # the name you chose in the function call.  
11 # Be careful not to override them in the next nodes.  
12 # Example : sendTheseDataToNextNodes(foo=a, toto=toto)  
13 # will make a accessible on the next nodes with the name foo, so you can use  
14 # as an already existing var, and toto will be accessible as toto  
15 # !! To send a, you can't write (a), please use (a=a)  
16 sendTheseDataToNextNodes(a=temperatures, hello=months)
```

On the right, the 'Visualisation' node configuration is shown, including a 'Name' field, a 'Please select the results you want to see on the chart' section (with 'a' selected), an 'X-Axis' section (with 'Please select the abscissa' selected), and a 'Type of chart' section (with 'line' selected). Below the configuration, a line chart displays two data series over a 12-month period (Jan to Dec). The Y-axis ranges from 0 to 30. The first series (blue line) has values: 7, 6.9, 9.5, 14.5, 18.4, 21.5, 25.2, 26.5, 23.3, 18.3, 13.9, 9.6. The second series (black line) has values: 3.9, 4.2, 5.7, 8.5, 11.9, 15.2, 17, 16.6, 14.2, 10.3, 6.6, 4.8.

in collaboration with



# Take Away Messages

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- ▶ From MDE to SLE
  - ▶ Language workbenches support DS(M)L development
- ▶ On the globalization of modeling languages
  - ▶ Integrate heterogeneous models representing different engineering concerns
  - ▶ Language interfaces to support structural and behavioral relationships between domains (i.e., DSLs)
- ▶ From software systems to smart CPS
  - ▶ Interactions with the physical world limited to (i.e., fixed, in closed world) control laws and data from the sensors
  - ▶ What about the broader context in which the system involves?
    - ▶ Physical / social / economic laws
    - ▶ Predictive models
    - ▶ Regulations, user preferences

# Conclusion

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- ▶ Integration of scientific models in the control loop of smart CPS is key to provide more informed decisions, a broader engagement, and eventually relevant runtime reconfigurations
- ▶ SEER is a particular instantiation of such a vision for sustainability systems

# Open Challenges

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- ▶ Diversity/complexity of DSL relationships
  - ▶ Far beyond structural/behavioral alignment, refinement, decomposition
  - ▶ Separation of concerns vs. Zoom-in/Zoom-out
- ▶ Live and collaborative (meta)modeling
  - ▶ Minimize the round trip between the DSL specification, the model, and its application (interpretation/compilation)
  - ▶ Model experiencing environments (MEEs): what-if/for scenarios, trade-off analysis, design-space exploration
- ▶ Integration of analysis and predictive models into DSL semantics
  - ▶ Towards unpredictable languages
    - ▶ *Specify the correctness envelope to avoid over-specification*
    - ▶ *Identify plastic computation zones*
    - ▶ *Vary the execution flow of the program*