Agent-based simulations to obtain a sector- and site-specific inventory

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DF 64 — Novel computational approaches in LCA

Thursday, 30 March 2017, ETH Zürich

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INTRODUCTION
Consequential LCA of complex/large systems

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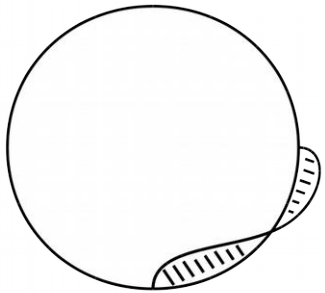
- Consequential Life Cycle Assessment
  - "… activities are included in the product system to the extent that they are expected to change as a consequence of a change in demand for the functional unit" (UNEP, 2011)
  - **Foreground consequences** modelled (over time, not only at long term market equilibrium)
  - Background consequences reflect changes of suppliers (e.g. marginal suppliers)

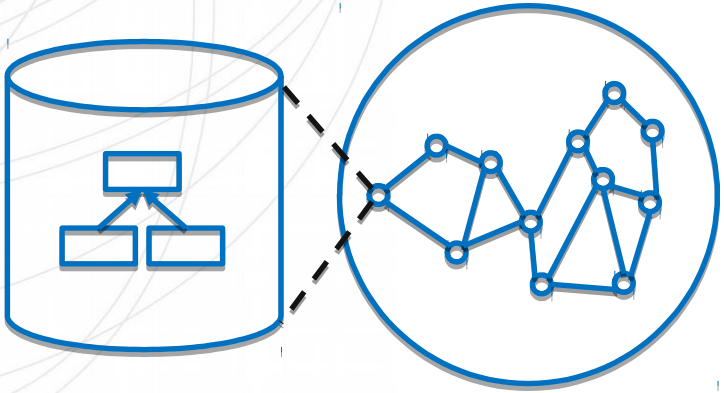


Adapted from Weidema, 2003

- Complex Systems
  - Great number of heterogeneous entities
  - Interactions among entities
  - Multiple levels of organization and structure

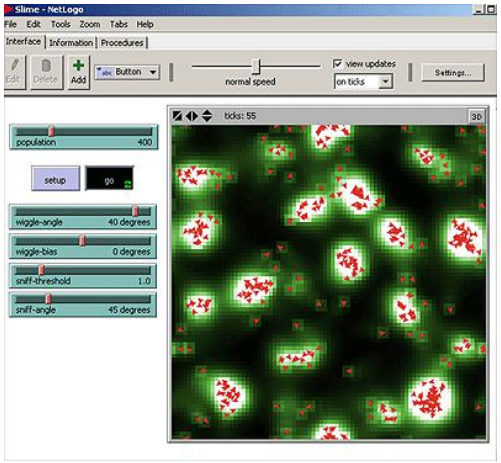
- **Foreground CLCA modelling of complex/large systems**
  - *Partial/Computable General equilibrium models (economy driven)*
  - *Behavior modeling (behavioral rules driven)*

INTRODUCTION
Agent Based Modelling

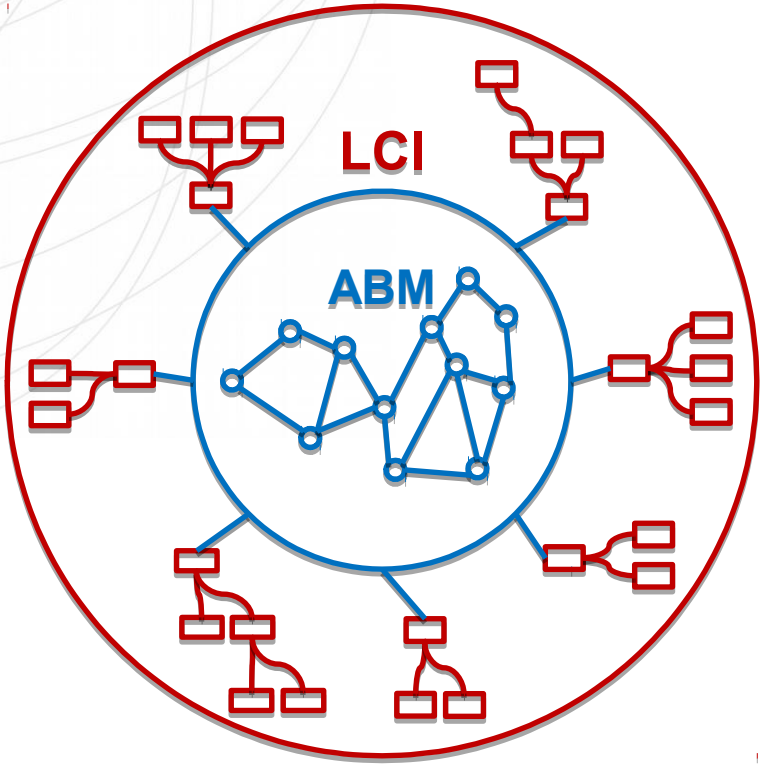


- Capture Complexity
  - Agents equivalent to entities
  - Modelling choice heuristics
  - Modelling entities Interactions
  - Observe structures/organization on different scale
- Computation Model

- Definition of ABM
  - Agents
  - Agent Organizations
  - Interactions
  - Environment



INTRODUCTION
ABM CLCA Coupling



- ABM enhanced LCA
  - ABM results inputs to LCI
- ABM/LCA Symbiosis
  - ABM results inputs to LCI
  - LCA results inputs to ABM (feed-back)

- Dynamic final demand vector
  - Agents represent consumers/actors
  - Models behavior in changing market
  - E.g. *Querini and Benetto, 2015*
- Dynamic technology matrix
  - Agents represent technologies/processes
  - Models structural changes of market
  - E.g. Davis et al., 2009

What can we do with ABM + CLCA ?

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- ABM to model complex systems
- LCI depends on the outputs of the ABM
- Uncertainty and sensitivity analysis from ABM to LCIA

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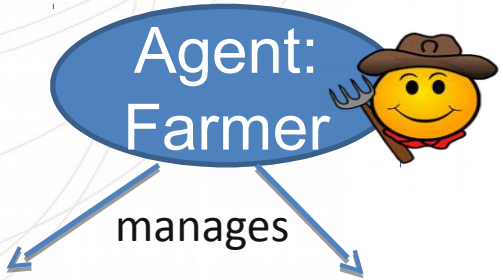
ABM to model complex systems (Agricultural sector, the case of Luxembourg)

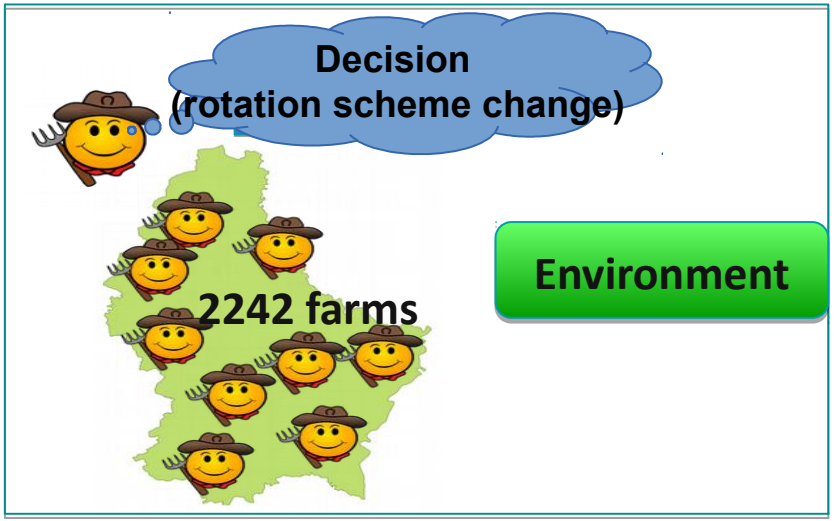
MUSA: MUlti agent Simulation for consequential Life Cycle Assessment of Agrosystems



Farm:
- ✓ *Size*
- ✓ Crop Rotation schemes

Crops (Cereals/Leafs):
- ✓ Yield
- ✓ Associated costs
- ✓ Fertilizer needs (N, P, K)
- ✓ Historical records on prices

Our own simulator



Behaviour & Rotation scheme

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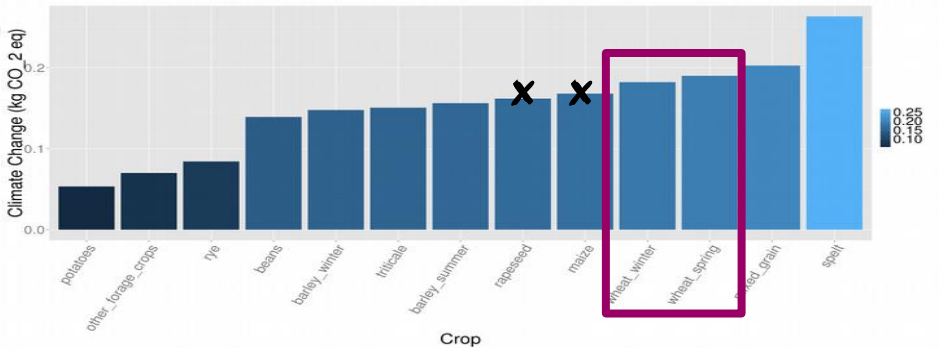
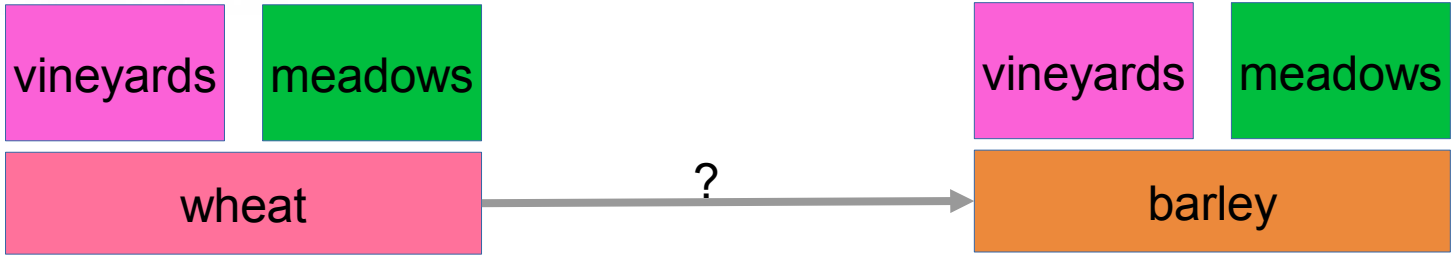
Agent



Farm



The MUSA model : i/o

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Inputs

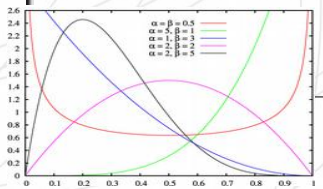
- How Many Farms
- How Many hectares of each crop were planted in 2009
- Distribution of farm size
- Statistics from specific survey (risk aversion)

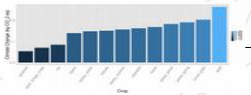
Outputs

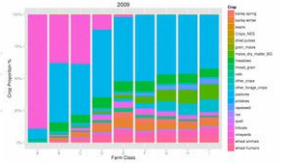
- How Many hectares of each crop will be planted ***after simulation***
- Environmental assessment based on the production (of crops)

LCI depends on the outputs of the ABM

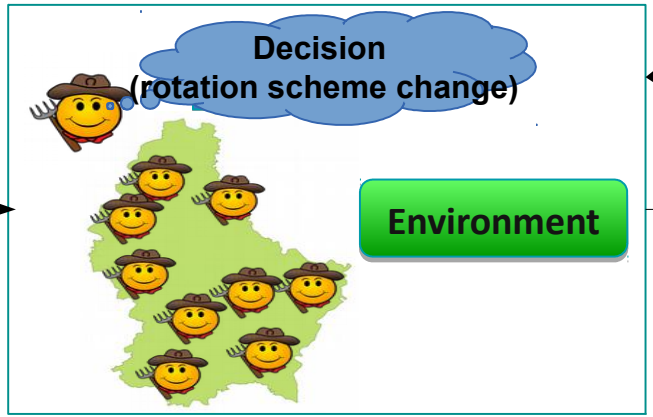
Coupling overview

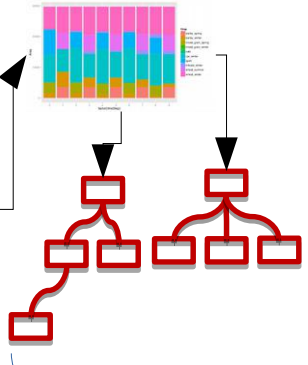


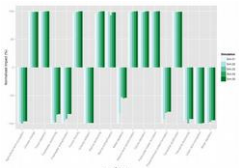




Scenario







LCI

LCIA

XML

Java

+ Bash scripting

Brightway2

Close to innovation

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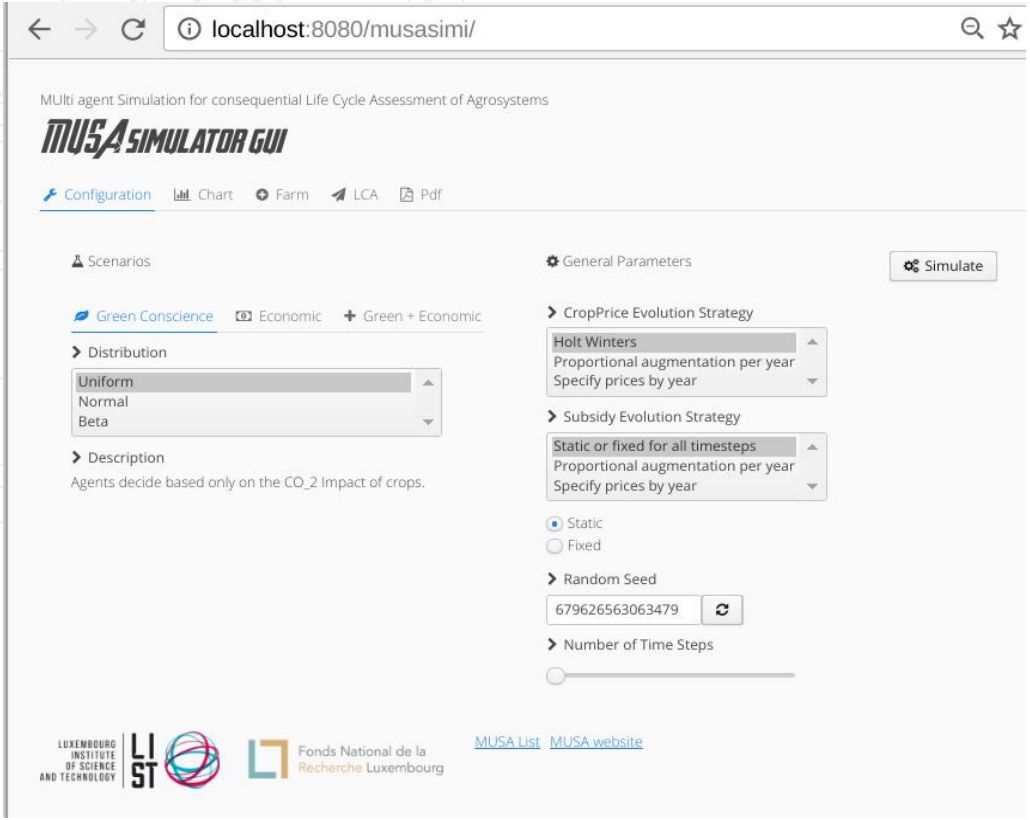

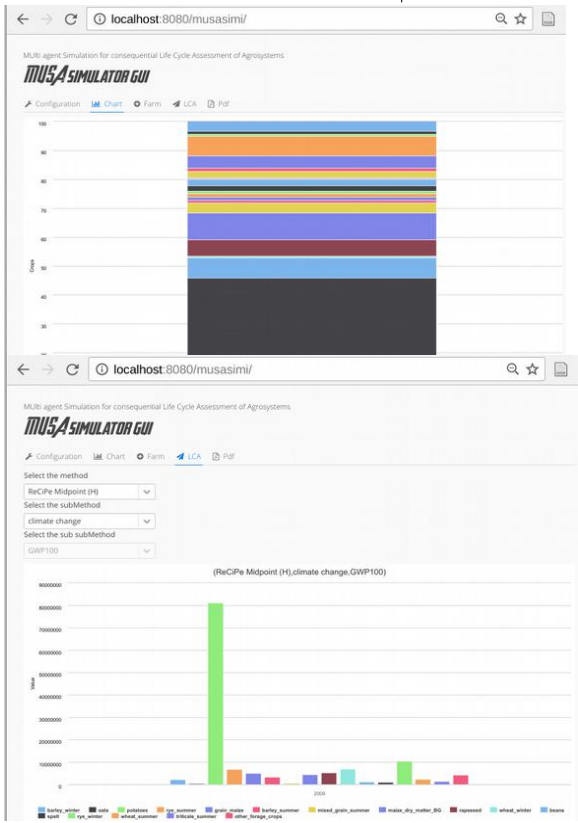

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Uncertainty and sensitivity analysis from ABM to LCIA

Uncertainty in ABM-LCA coupled models

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- Sources of uncertainty in ABM part
  - Uncertainty in quantities
  - Uncertainty about the model
  - Stochastic error

- Sources of uncertainty in LCA part
  - Uncertainty in quantities
  - Uncertainty about the model

- Loosely coupled model
  - Model parts are run in series
  - Distributions of ABM outputs become input quantities of LCA
  - No input correlations between models accounted for
  - Different propagation methods can be applied to both model parts

- Fully coupled model
  - Models are run in parallel with alignment of simulations
  - Input correlations can be taken into account
  - Requires an uncertainty propagation method that suites both parts

- Taking into account stochastic error of ABM part
  - Several simulations for one concrete instance of ABM part (or the fully coupled model)
  - Averaging over each instance if stochastic error is not meaningful

Uncertainty propagation for ABM + CLCA framework

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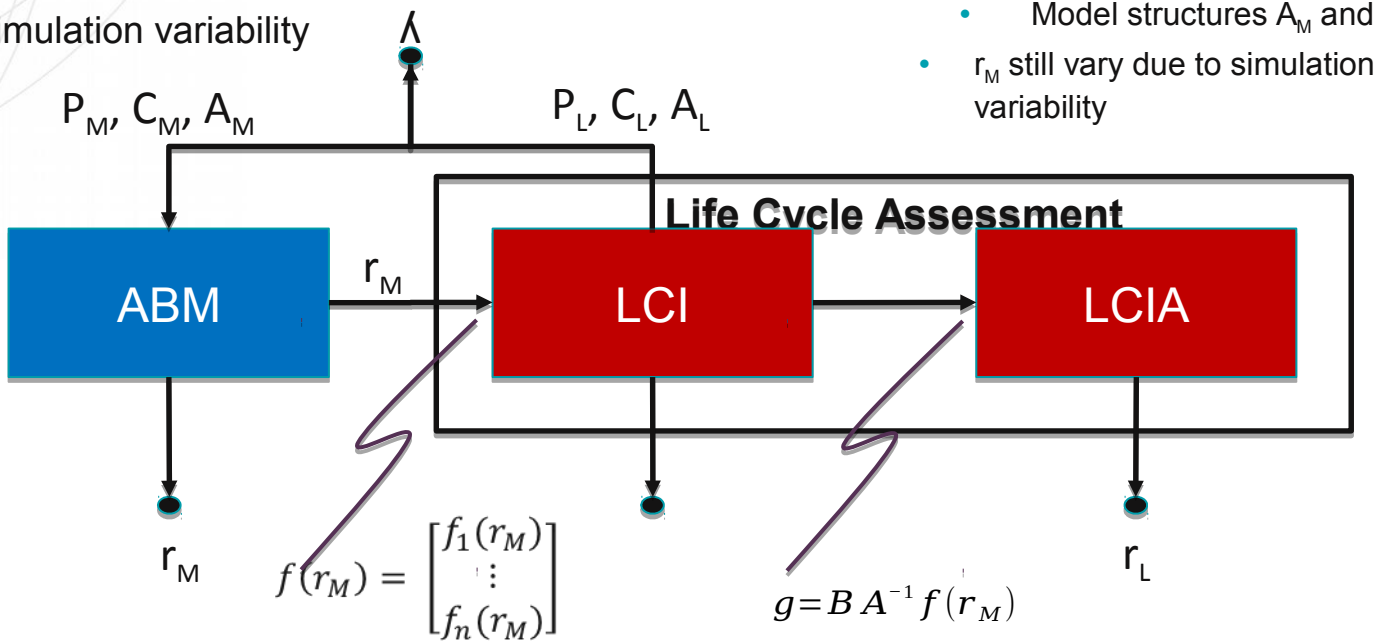
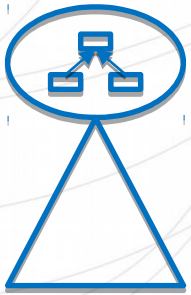
- Uncertainty Sources:
  - Parameter uncertainty
  - Model uncertainty
  - Choice uncertainty
  - Simulation variability

- **Nomenclature:**
  - Λ is one concrete instance of:
    - Parameters P_M and P_L
    - Choices C_M and C_L
    - Model structures A_M and A_L
  - r_M still vary due to simulation variability



Uncertainty separation



Inner Loop

- Population characteristics
  - Green Conscience (GC)
  - Risk Aversion (RA)
  - Window Size (WS)
- Agents choices
  - Crop choice

Outer Loop

- Distribution parameters
  - GC: α and β of beta-distribution
  - RA: α and β of beta-distribution
  - WS: max of uniform distribution
- Initialization parameters
  - Farm sizes
  - Initial crops
  - Initial rotation schemes
- LCI background parameters
  - Technosphere matrix
  - Biosphere matrix
  - Based on Ecoinvent2.2

Implementation

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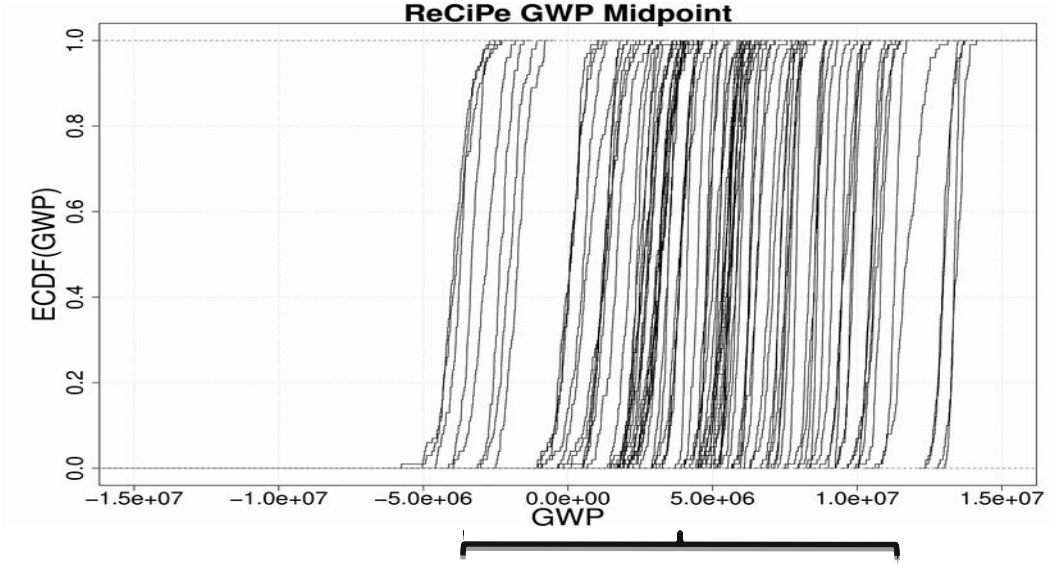
- Sequencing
  - 100 outer loops
    - concrete instances λ
  - 100 inner loops
- Horsetail plot
  - One ECDF for each λ
- Distance between CDF
  - Epistemic / background uncertainty
- Width of CDFs
  - Aleatory uncertainty



Epistemic / background uncertainty

Accuracy, Applicability and Computation time

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Accuracy

- Include correlations
  - Among and across models
- Uncertainty separation
- Accurate sensitivity analysis

Applicability

- Coding lines
  - Total lines 9.2k
  - Additional lines 900
- Coding time
  - Total: 6 month
  - Additional: 15 days

Computation time

- Computation times
  - 5 hours foreground
  - 3 hours background
- High number of simulations (10’000)
- Unfeasible for heavier models

Outlook for uncertainty propagation

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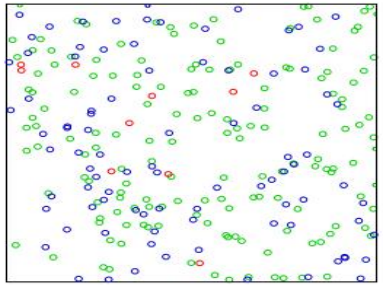
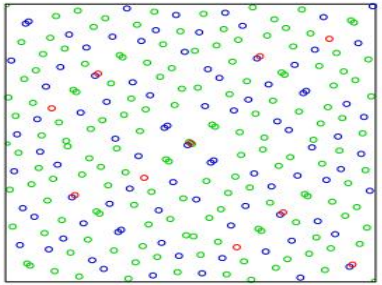
- Advanced sampling schemes
  - Latin Hypercube
  - Quasi random sampling
- Simple Monte Carlo
  - Reduction of # of simulations
- Global Sensitivity analysis
  - Contribution to variance
  - Averaging over inner loops
  - Sobol indices
- Mobility Case Study





Final note

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- Complex System + CLCA → ABM
- Computational nature of ABM → simulation, quick transfer to application
- Model → uncertainty propagation is possible

Computational Life cycle Assessment Community : UNITE !

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Traditional meetings (LCM, SETAC, …)

- No dedicated tracks for computational aspects
- Broad in scope
- Funding can limit attendance
- Mostly one way interaction

Workshops ?

- Funding by organizing institution
- Narrow scope

CLAC COST ACTION

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Let's make it happen !

How ?

+ Travel / Organizing funding
+ EU level

+ Hackaton ?
+ Workshops ?
+ Keynotes ?
+ Manifesto ?
+ Short sci. visits ?
All !

Who ?

Organizers:

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& Friends ;)

Come see us, let's start (next collection date: September 2017)

DON’T FORGET!

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