The GLOWA-Danube Approach to Integrative Environmental Simulations

Rolf Hennicker

Ludwig-Maximilans-Universität München

gefördert vom Bundesministerium für Bildung und Forschung

Integrative Techniques, Scenarios and Strategies for the Future of Water in the Upper Danube Basin (2000 – 2010)

The GLOWA-Danube Project

Natural Sciences
- Hydrology
- Plant Ecology
- Glaciology
- Meteorology
- Groundwater
- Surface Water

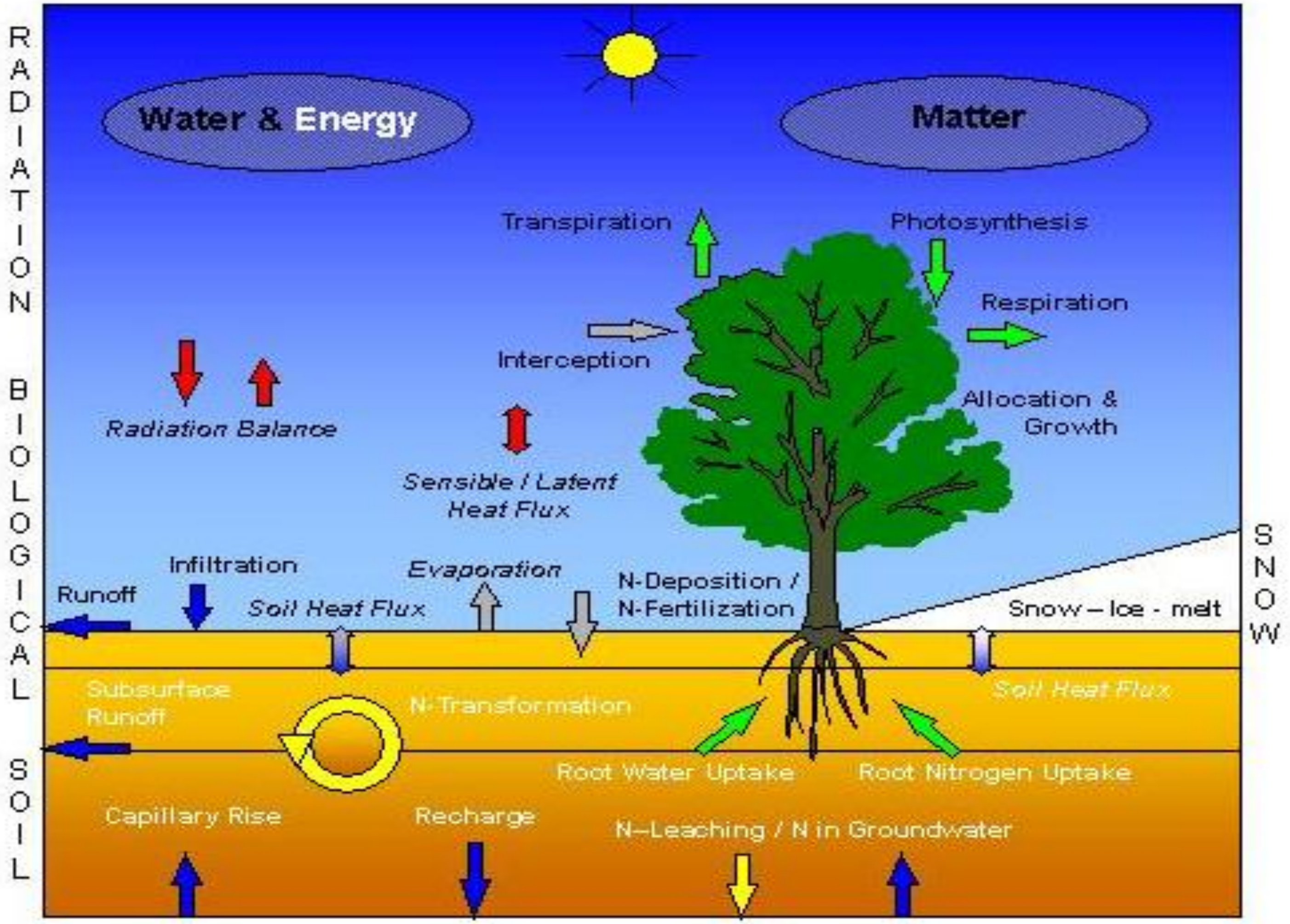
Social Sciences
- Environmental Psychology
- Environmental Economy
- Tourism Research
- Water Supply
- Agricultural Economics

+ Informatics

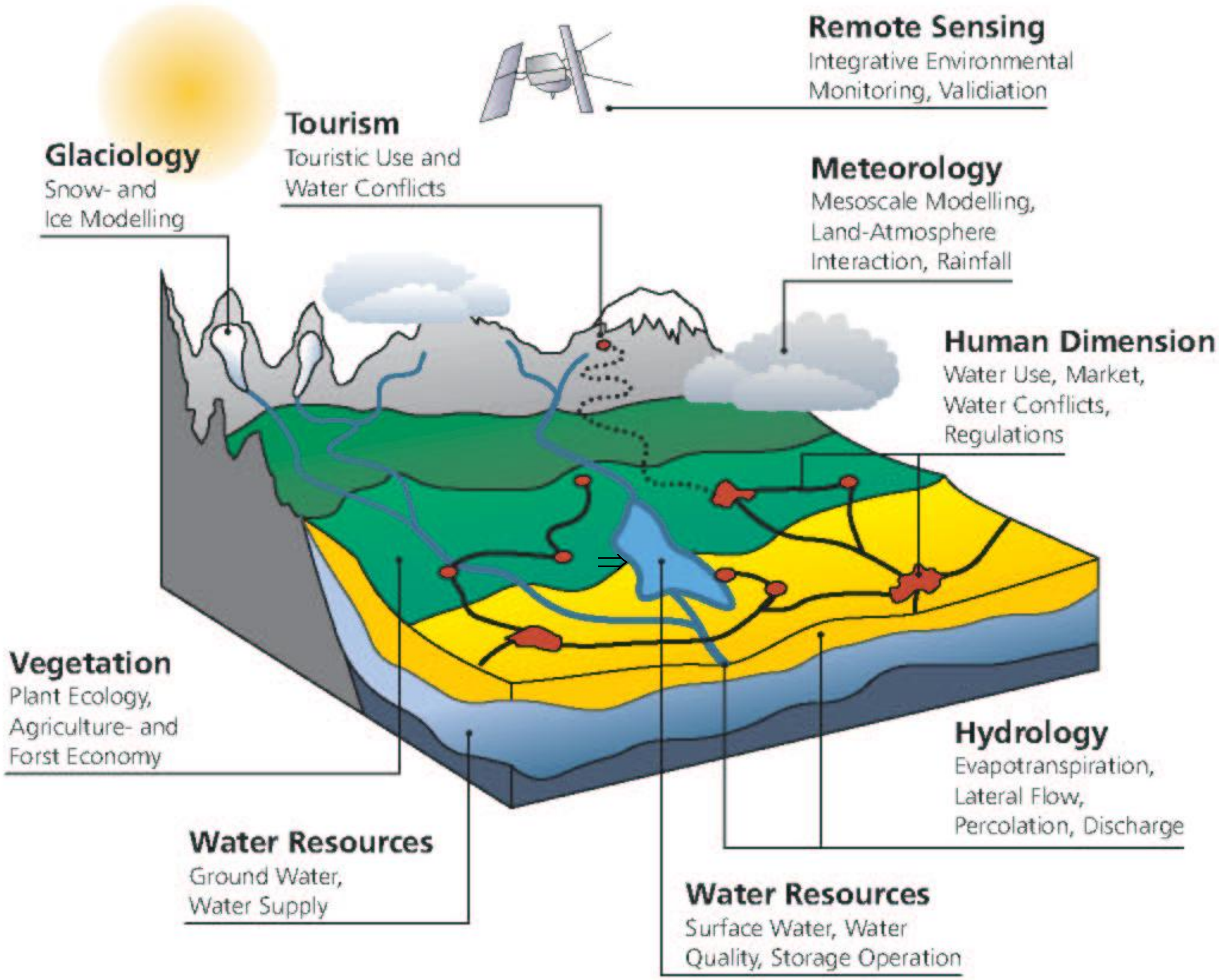
Upper Danube Basin:
- Area: 77.000 km²
- Population: 8.2 Mio.
- Elevation Gradient: 3300 m



Mutually Dependent Processes in Nature



Mutually Dependent Processes in Nature <u>and</u> Society



- "Stand-alone" modelling of the single processes is not sufficient
- An integrative view is needed → **system of coupled simulation models**

General Goal

Development of an integrative platform for

- **coupled simulations** of various models of natural-science and socio-economic disciplines
- analysis of the effects of **mutually dependent processes** (including "acting" entities like *farmers, housholds, water-suppliers, touristic actors*)
- decision support on the basis of **environmental scenarios** under the conditions of **global climate change**

Current version of the system

- integrates 17 simulation models developed by the project groups
- runs on a computer cluster with more than 50 processors
- the simulation models ***run in parallel*** and exchange data at run-time

Requirements for Coupled Simulations

- **Data exchange** (between the different models) via interfaces
- Consistent modelling of the **simulation space**
- **Parallel execution** of (dependent) simulation models
- Treatment of **time** (life cycle and coordination of simulation models)
- Modelling of **acting entities** (agents),

  like *farmers, water suppliers, households, touristic actors*

Development Principles

- ***Common graphical modeling language (UML)*** used by all project groups for the documentation of interfaces, concepts and designs
- ***Framework technology*** to facilitate the integration of simulation models
- ***Object-oriented approach*** in all development phases (system analysis, design and programming)
- ***Formal methods*** to verify critical parts of the coupled simulation system

Outline of the talk

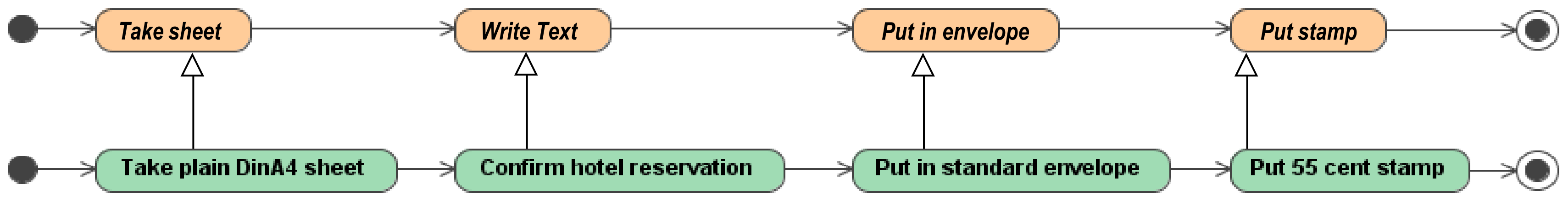
- The framework idea
- Crucial aspects of coupled simulations:
  - Data exchange
  - Simulation space
  - Simulation time: life cycle and coordination
- System architecture
- The Actor framework for agent-based social simulations
- System application:
  - Workflow
  - Scenarios
  - Simulation configuration and monitoring
  - Simulation results
- Example for interaction nature - actors
- Conclusion

The Framework Idea

- Extract common properties and rules which hold ***for all*** simulation models and implement them in a general, abstract ***template***.
- The model developer must only implement the ***open pieces*** of the template (according to his/her domain).

Example (writing a letter)

abstract template

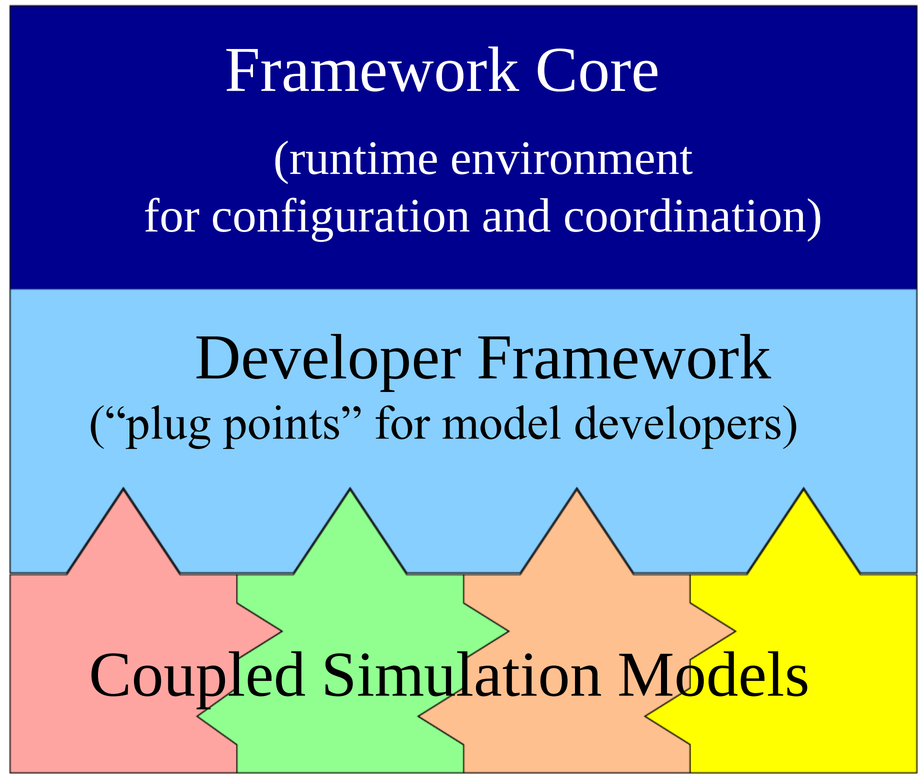


concrete instantiation

Framework Principle for Coupled Simulations

Framework Architecture

Integrative Simulation System
DANUBIA



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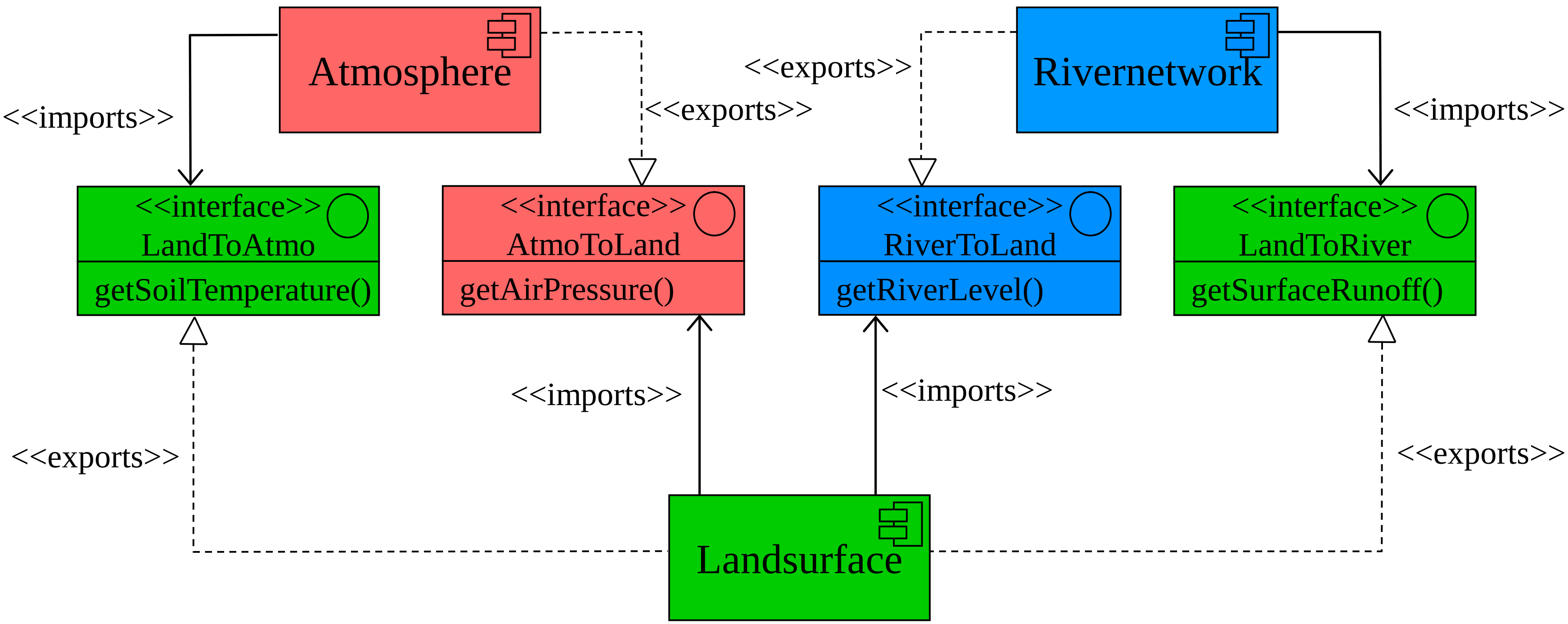
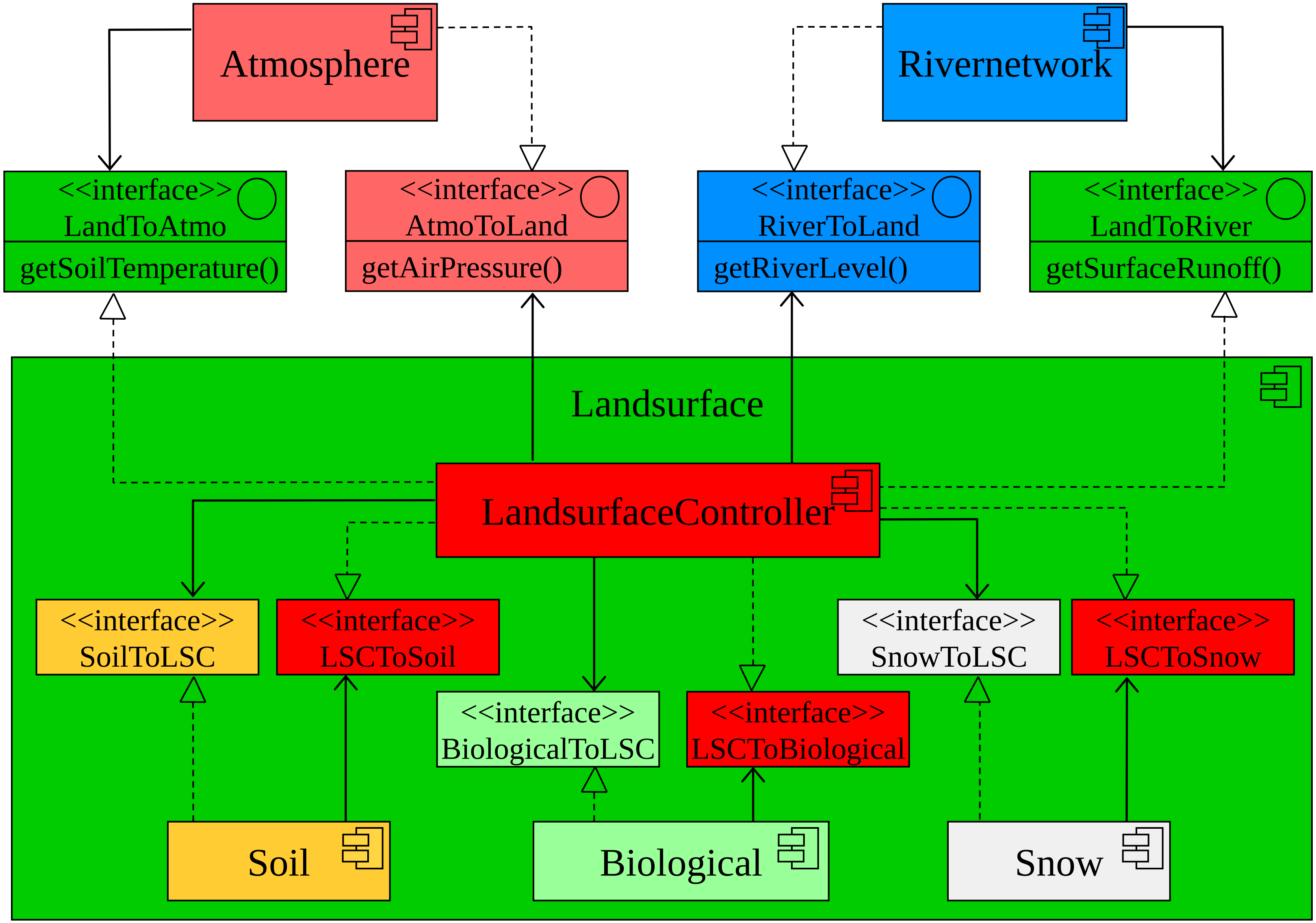
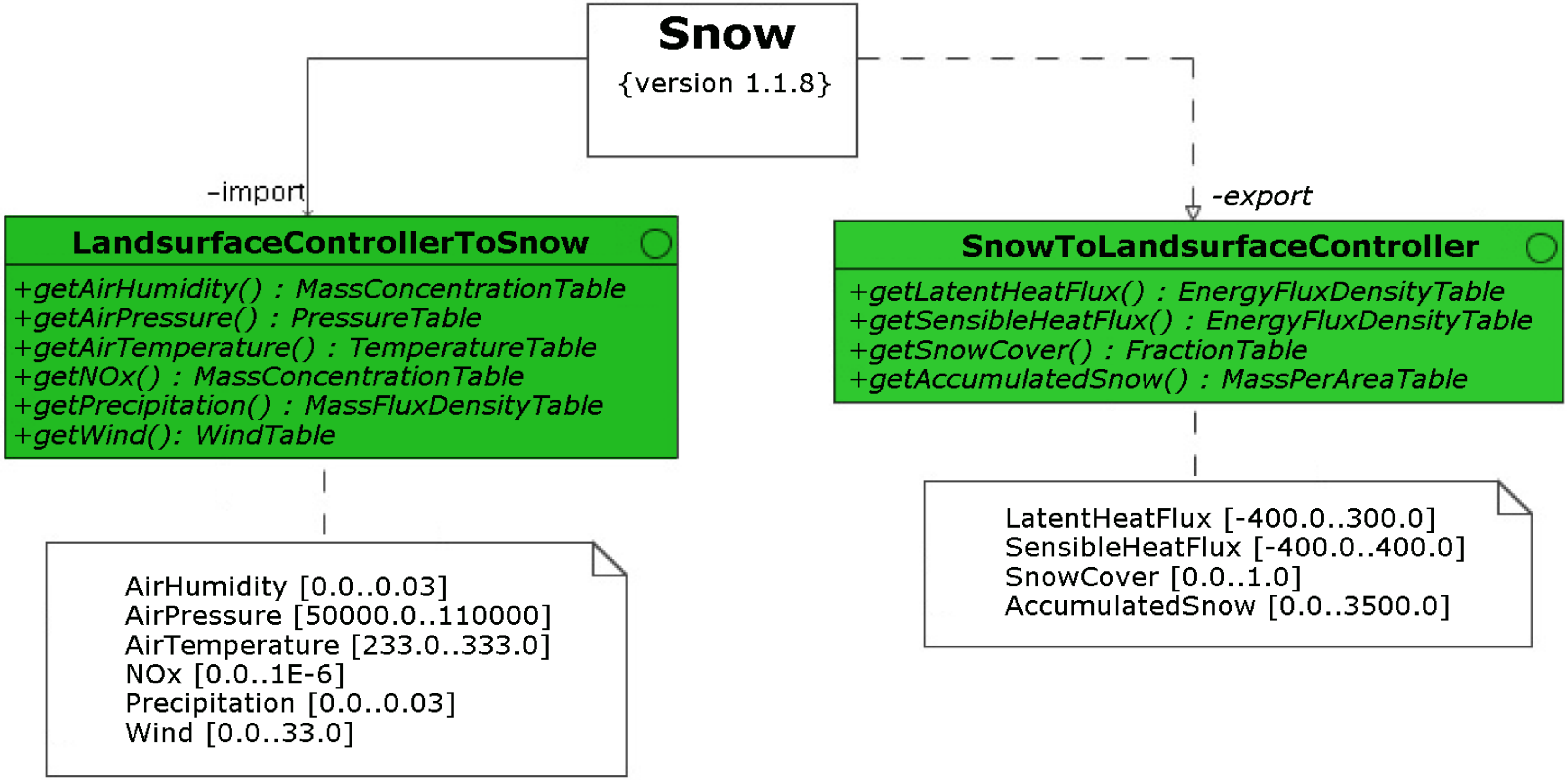
Data Exchange: Modelling of Interfaces



Hierarchical Structure



Specification of Interfaces



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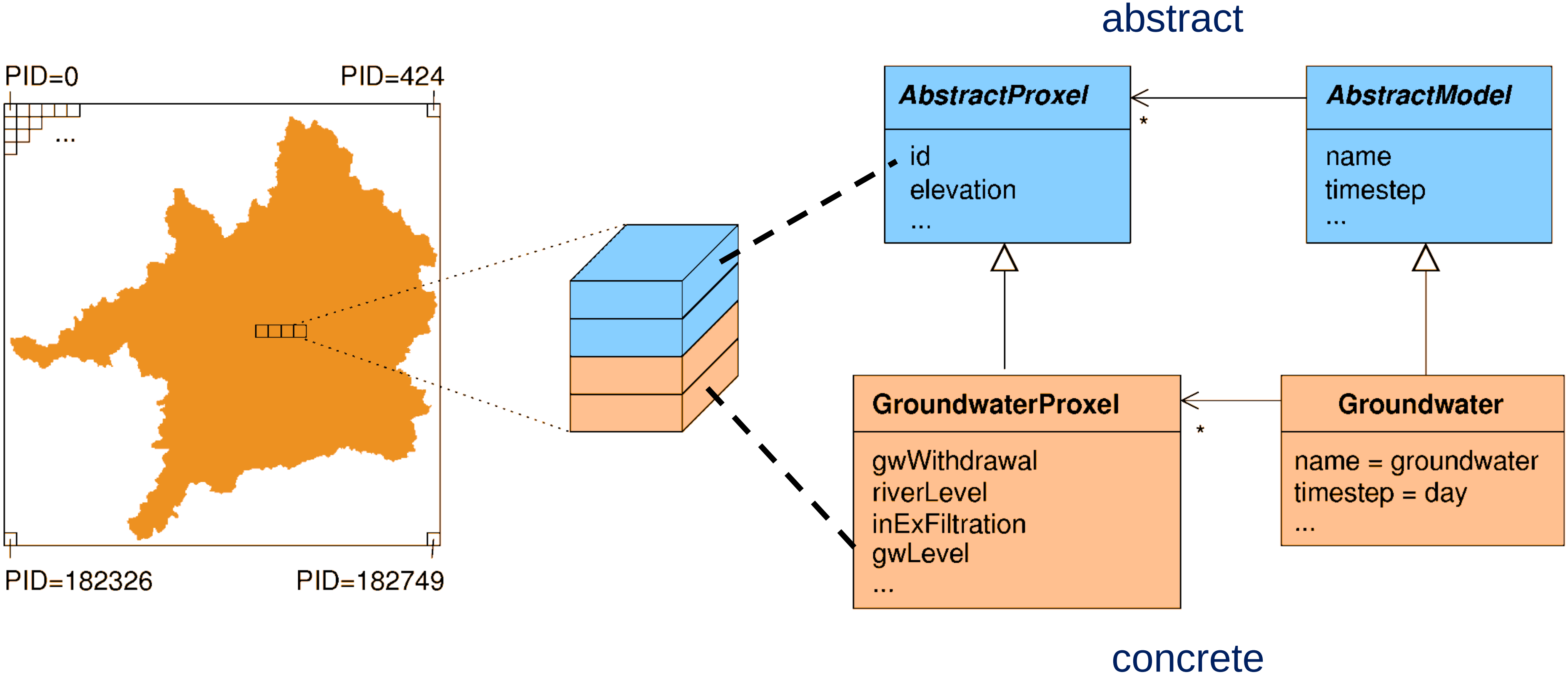
Simulation Space: The Proxel Concept

Approach

- a simulation area consists of a set of "**proxels**" (process pixels, 1km x 1km)
- each proxel can be identified by a **unique proxel id** (pid) and is modelled as an **object** which has a "state"
- **computations** are performed "proxelwise"



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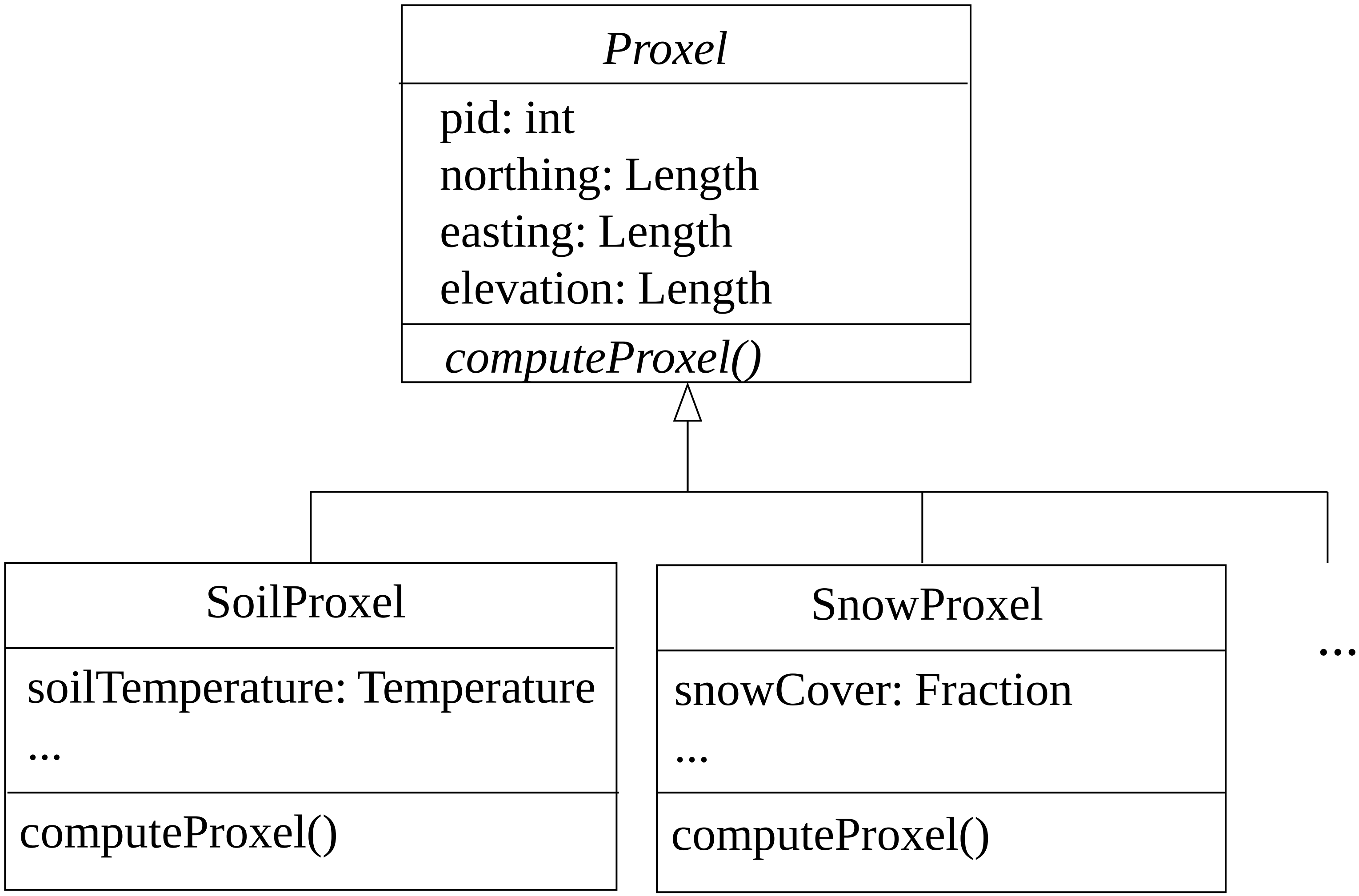
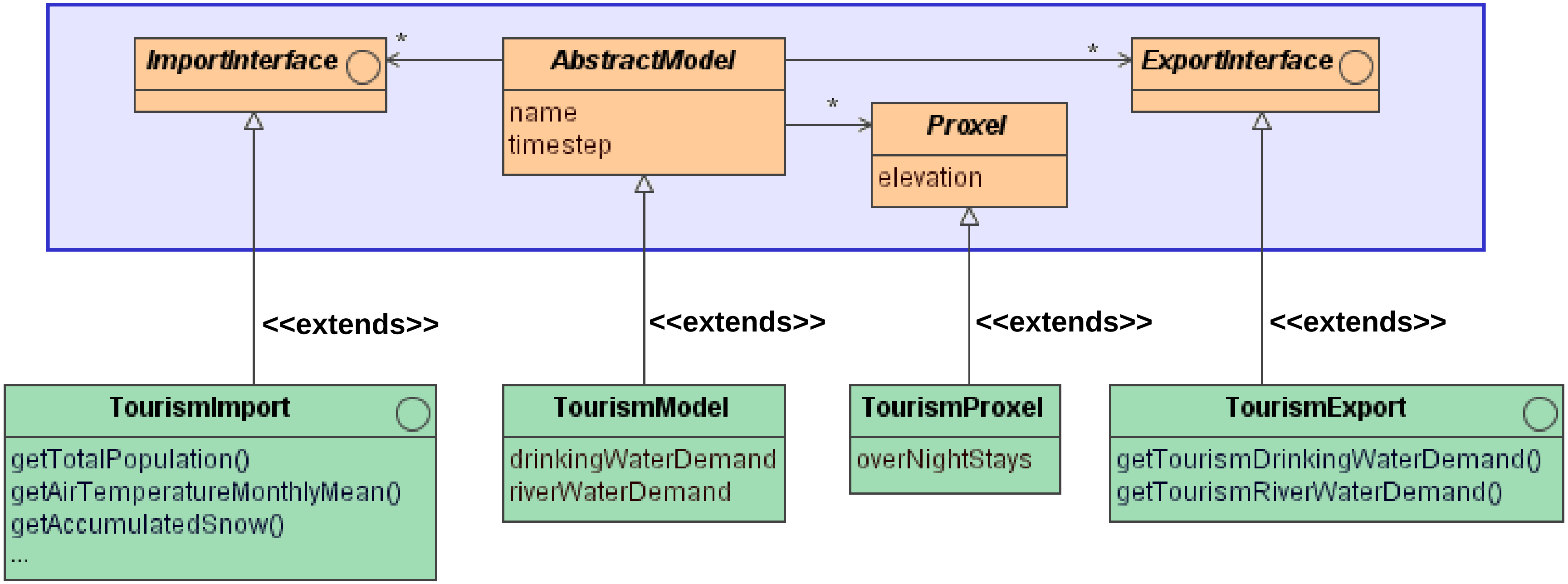
Proxel Hierarchy



The Developer Framework: Common Static Properties



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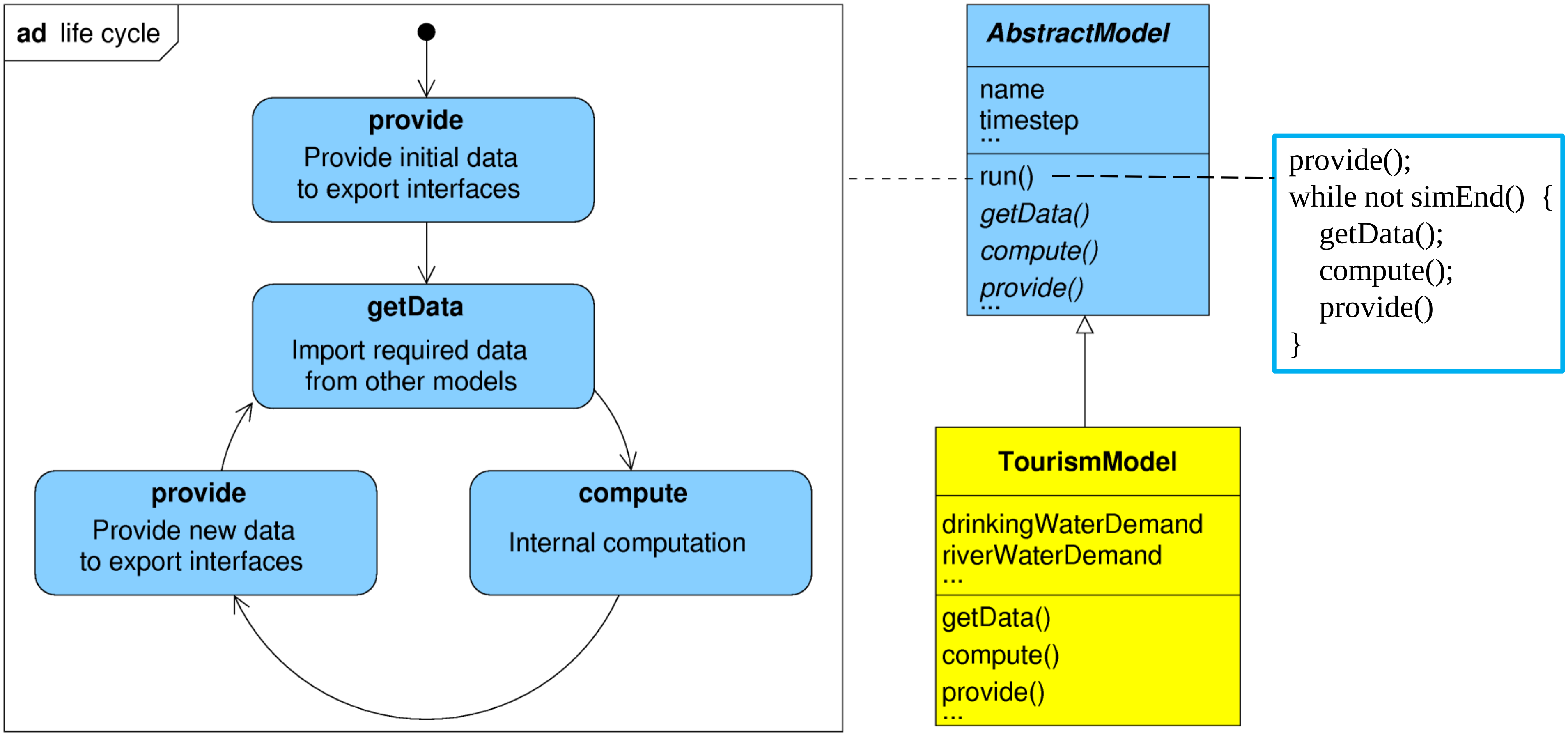
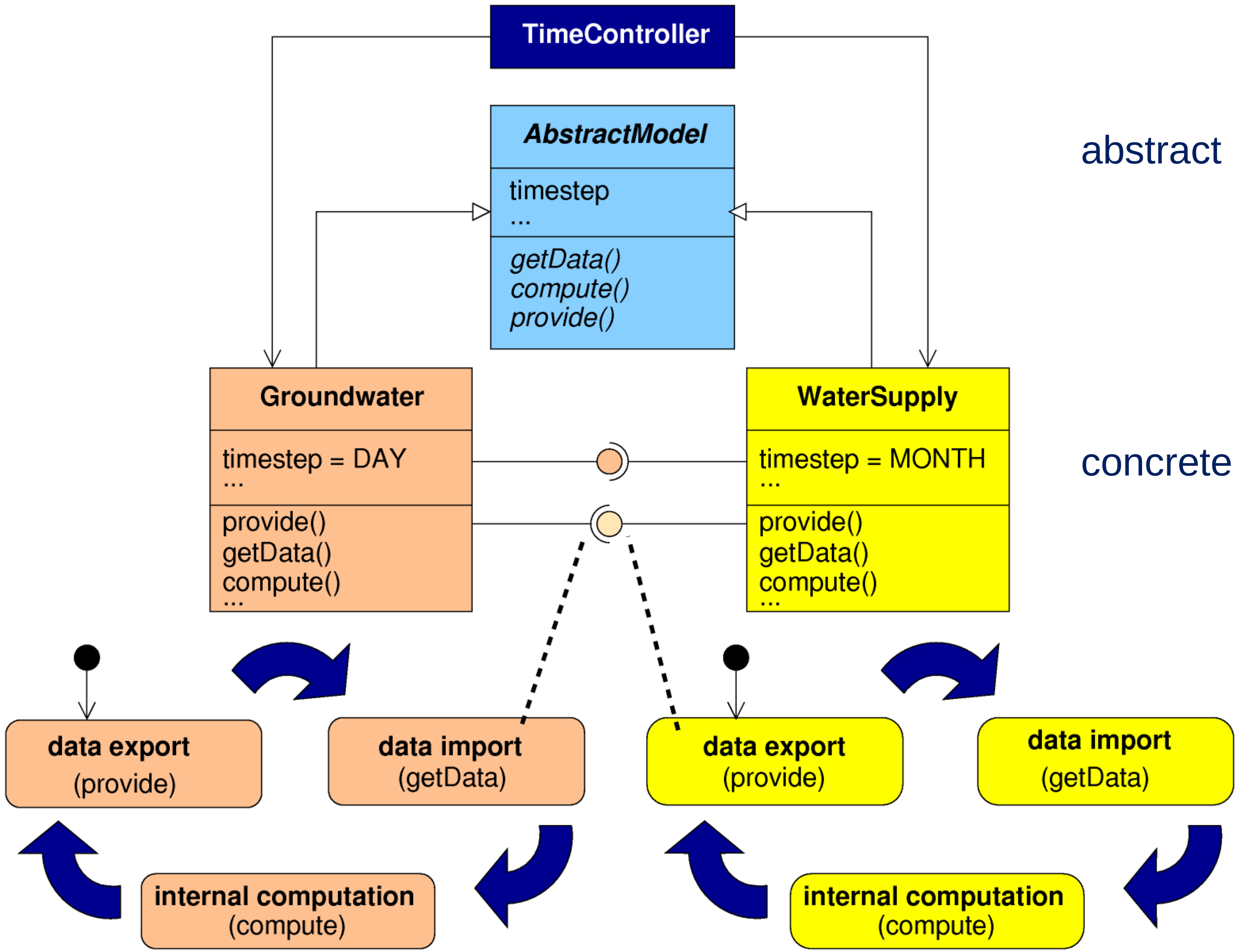
Common Life Cycle of Simulation Models



Coordination of Simulation Models



The Coordination Problem

- Each simulation model participating in an integrative simulation has an ***individual local time step*** (e.g. 1 h, 1 day, 1 month).
- Every simulation model must be supplied with ***valid data***, i. e. with data that fits to the local model time of the importing simulation model.

Example: M1 time step = 2, **M2** time step = 3

gets overwritten data!

M1 prov[t=0] get[t=0] comp prov[t=2] get[t=2]

M2 prov[t=0] get[t=0] comp prov[t=3] get[t=3]

gets obsolete data!

M1 prov[t=0] get[t=0] comp prov[t=2] get[t=2] comp prov[t=4] get[t=4]

M2 prov[t=0] get[t=0] comp

Formalisation of the Coordination Problem

Idea:

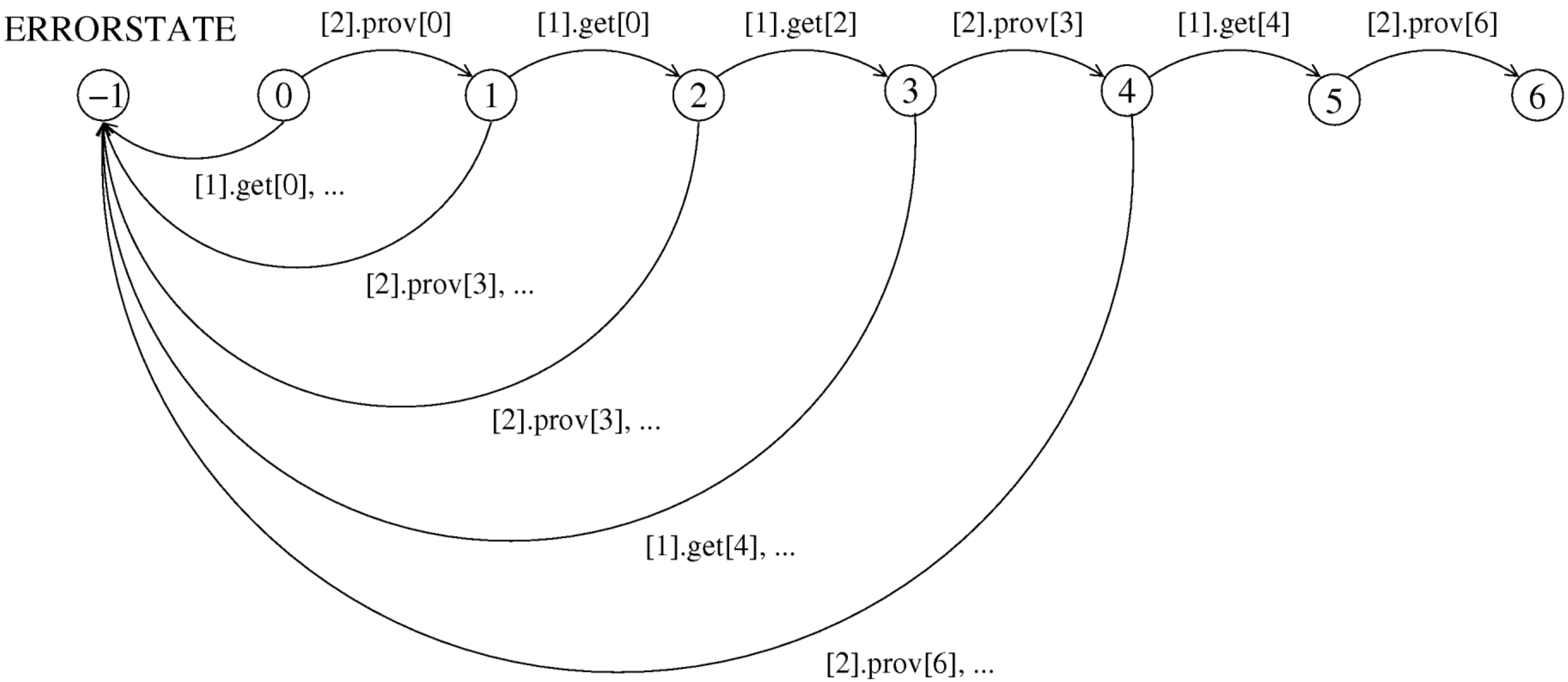
- Consider simulation models ***pairwise*** and only under ***one role*** at a time: either as a ***user*** or as a ***provider*** of data.
- A user must not get data "too early" *(no obsolete data)* and a provider must not deliver data "too early" *(no overwritten data).*

Process algebrac specification with FSP [Magee, Kramer]:

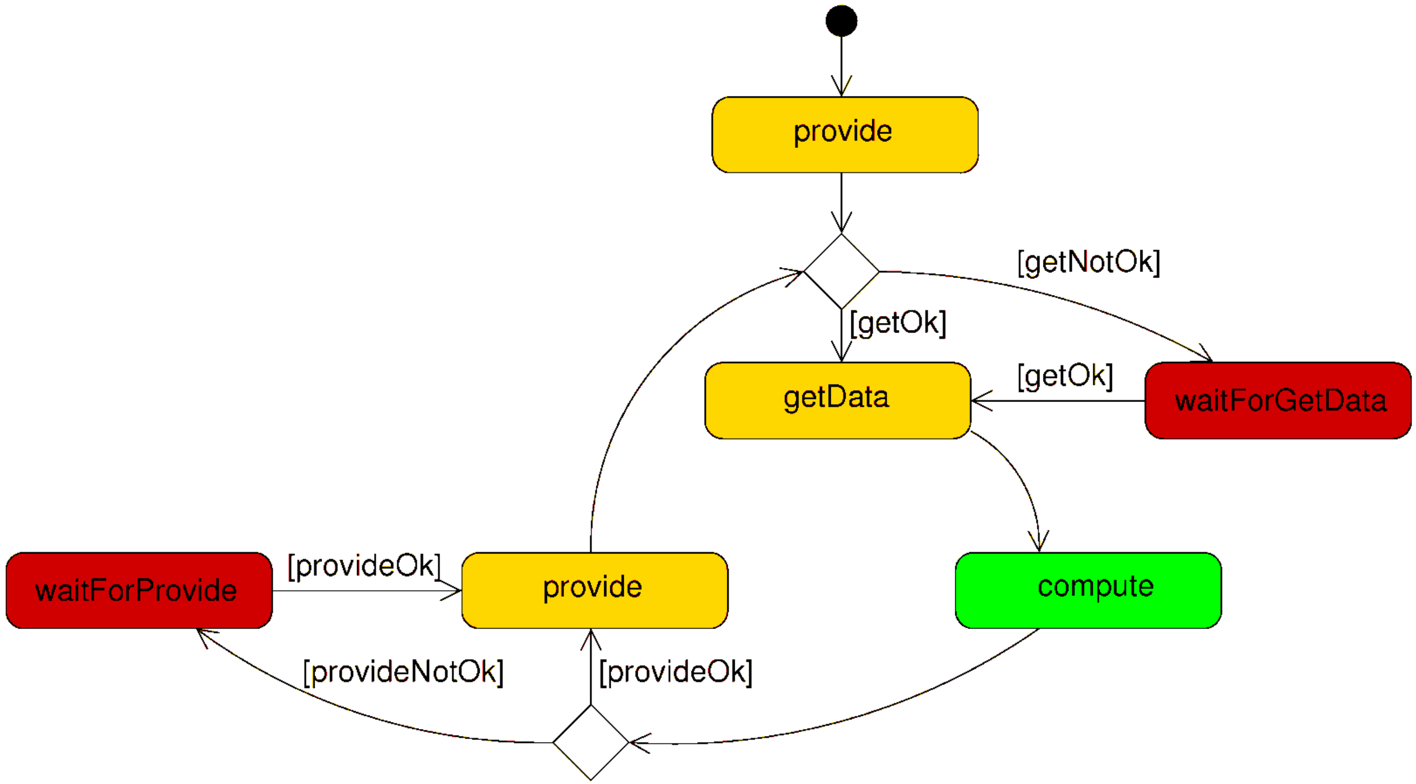
```
const simStart = 0
const simEnd = 6
range Time = simStart..simEnd

property VALIDDATA(User, StepUser, Prov, StepProv) = VD[simStart][simStart],

VD[nextGet:Time][nextProv:Time] =
  // no obsolete data
  (when (nextGet<nextProv)
    [User].get[nextGet] -> VD[nextGet+StepUser][nextProv]
  // no overwritten data
  |when not(nextGet<nextProv)
    [Prov].prov[nextProv] -> VD[nextGet][nextProv+StepProv]).
```

Labelled Transition System

```
VALIDDATA(User=1, StepUser=2, Prov=2, StepProv=3)
```

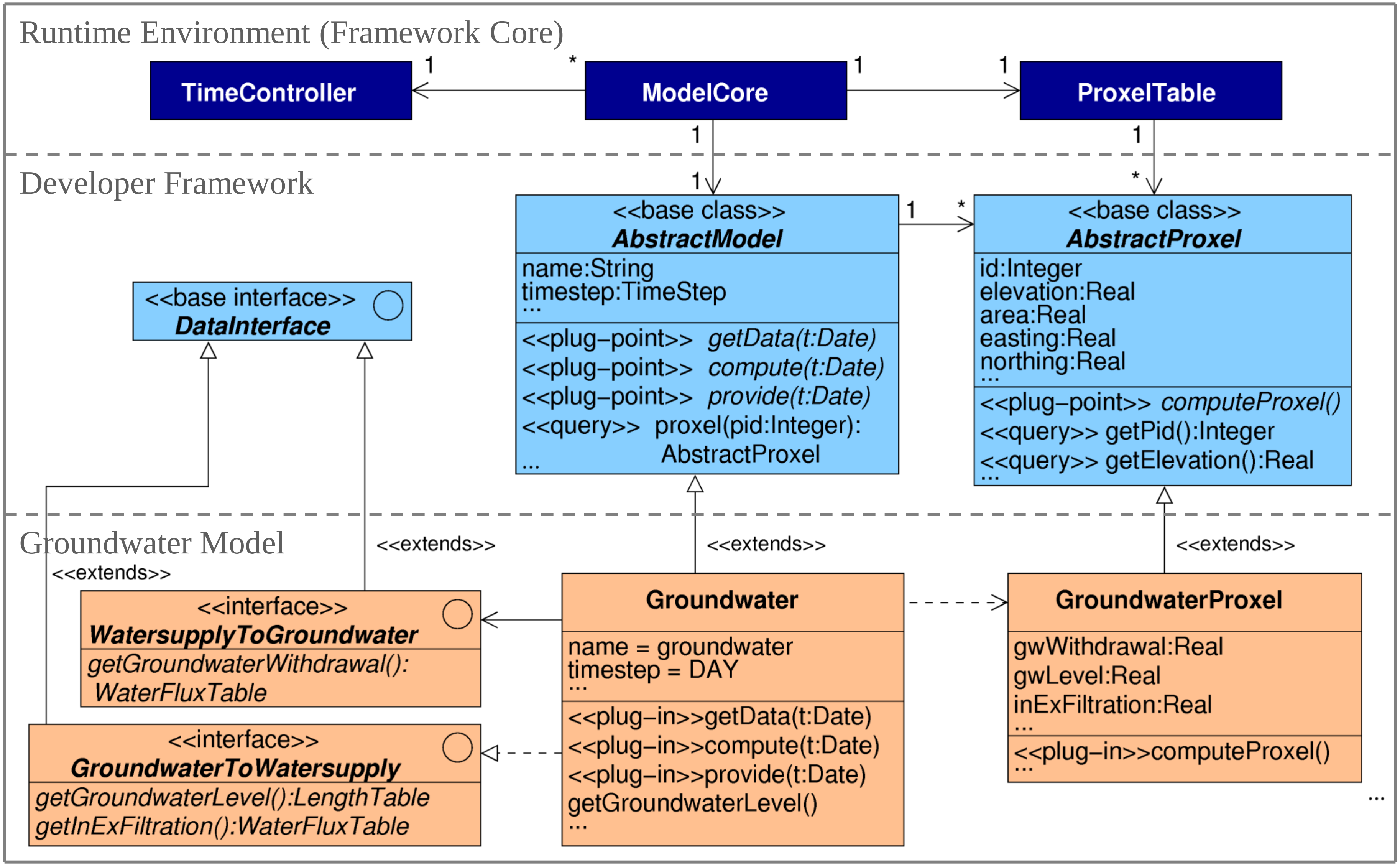


Coordinated Life Cycle of Simulation Models

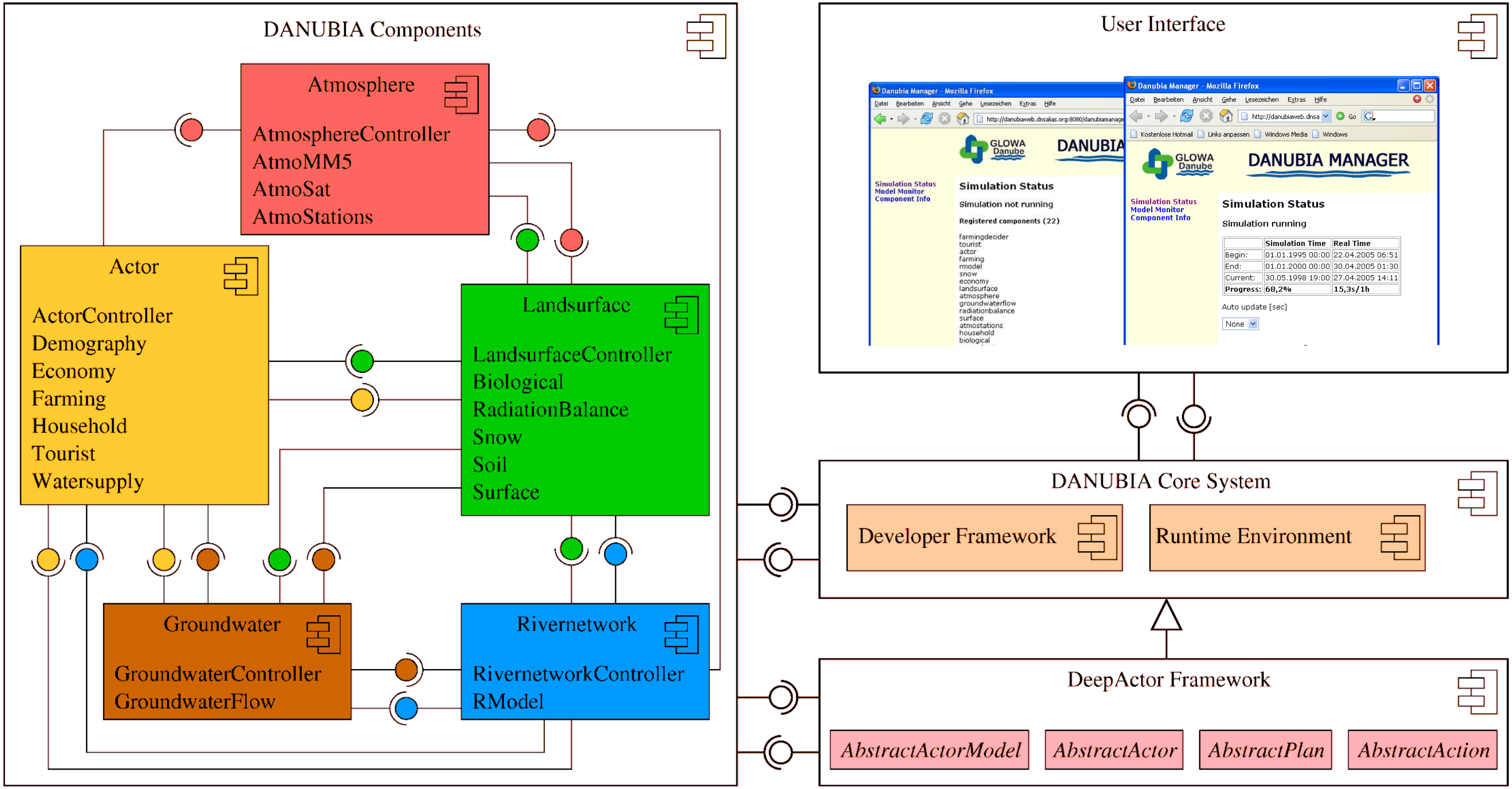


- A model is blocked (**waitForGetData**), if the coordination conditions for **getData** are not satisfied (analogously, **waitForProvide**).
- A global „**Timecontroller**“ monitors the coordination conditions.

Simulation Framework



System Architecture



Agent-based Social Simulations ("Actor Models")

- Integration of **decision-making** entities, called **actors**.

- Actors represent individuals or organisations
(e.g. households, farmers, touristic infrastructures, water-suppliers).

- Any actor can perform actions and has a repository of potential plans (**initial plans**).

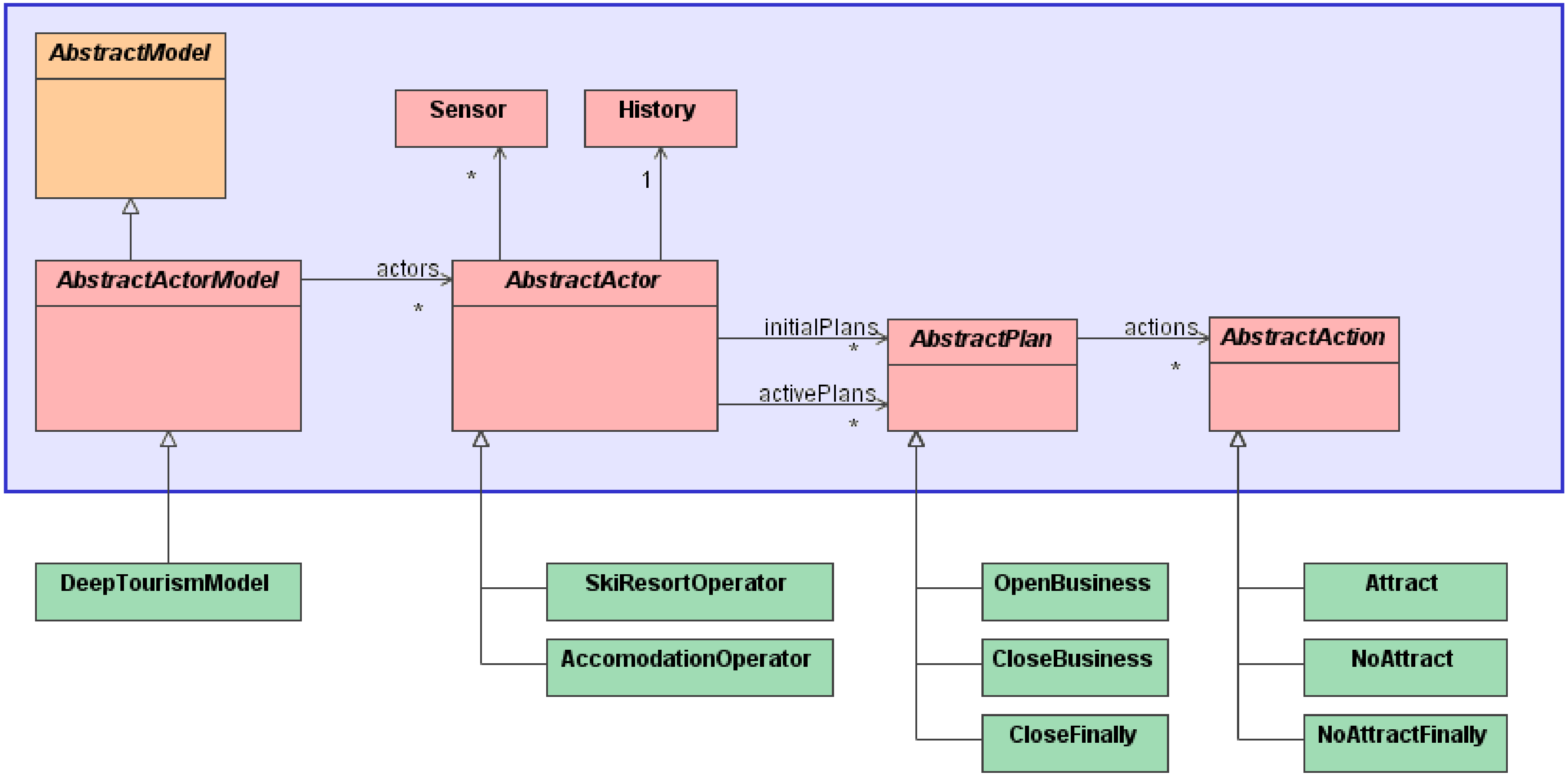
  Example: Farming-Actor
  Actions: Planting, Harvesting, Irrigating
  Plans: Choose crops for the next year → Landuse

- In each computation step an actor decides which of the initial plans should actually be executed (**active plans**)

- To support decisions each actor has
  - **sensors** through which it can observe the "environment" and
  - a **history** to remember previous decisions.

Structural Properties of Each Actor Model

Actor Framework



Actor Framework Instantiation

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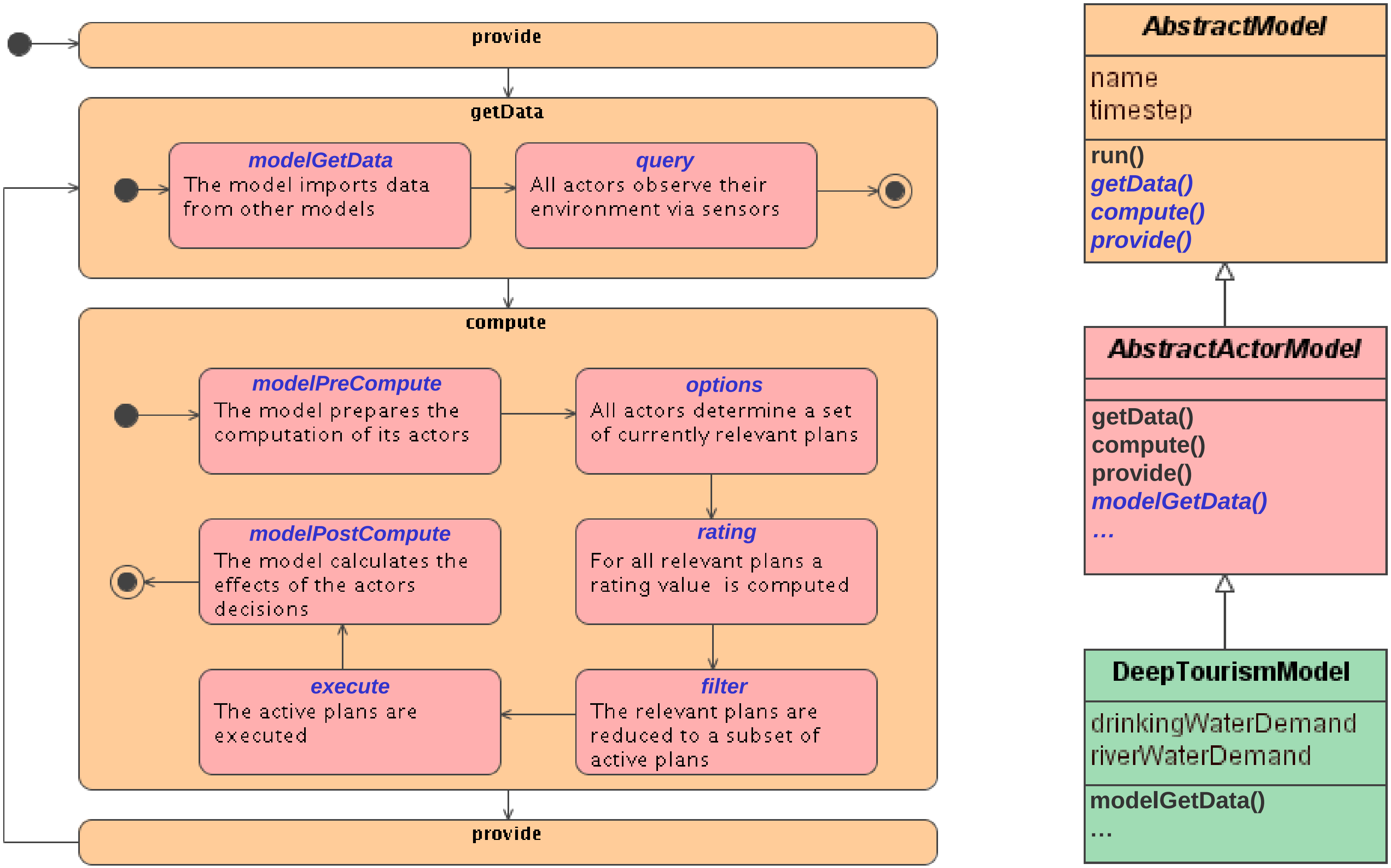
Common Life Cycle of Each Actor Model

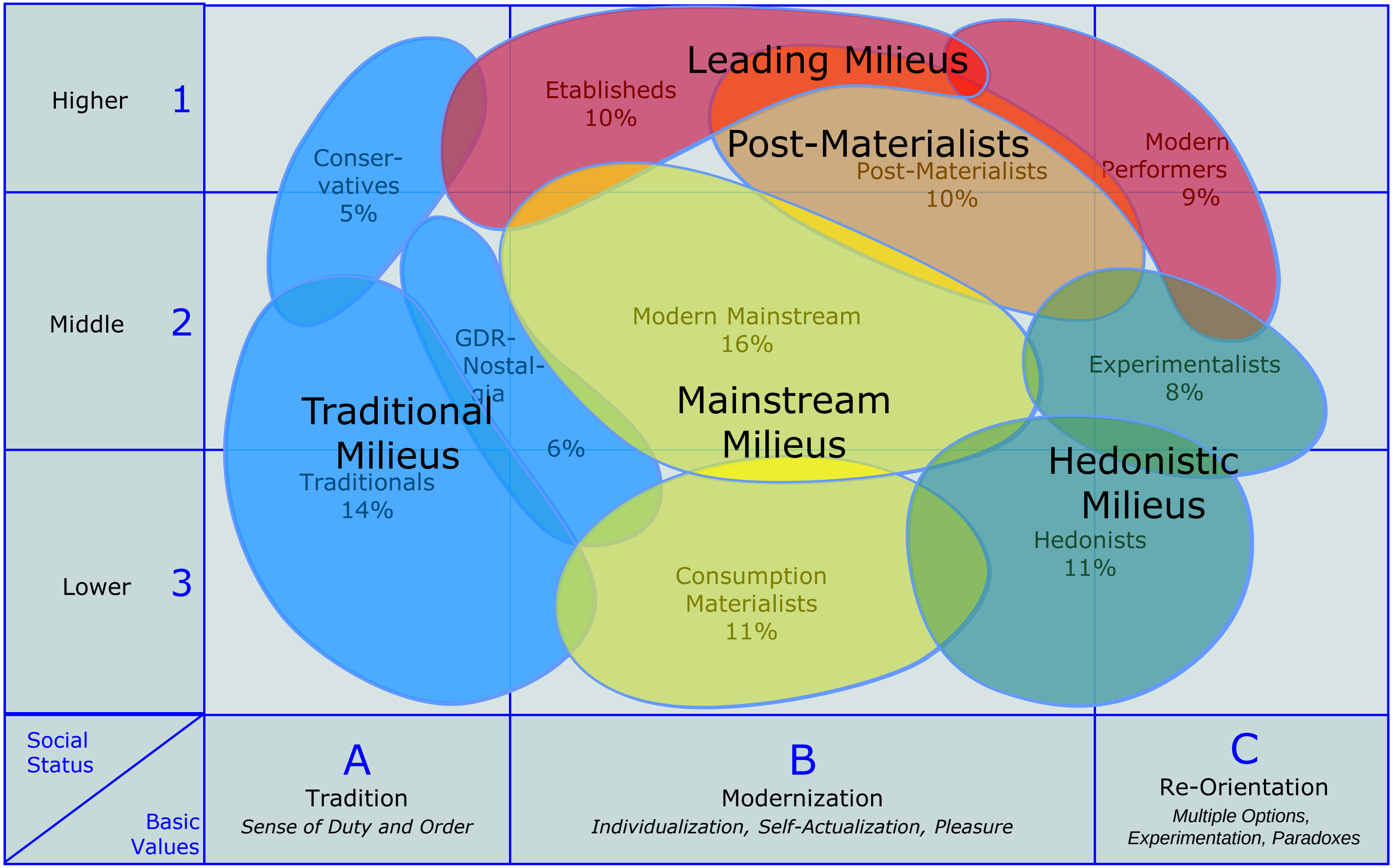


Actors in DANUBIA

Modell (Teilprojekt)	*DeepHousehold* (Umweltpsychologie)	*DeepWaterSupply* (Wasserversorgung)	*DeepTourism* (Tourismusforschung)	*DeepFarming* (Agrarökonomie)	*DeepEconomy* (Umweltökonomie)	*DeepDemography* (Umweltökonomie)
Konzept	Akteur repräsentiert Haushalte eines Proxels	Akteur repräsentiert Wasserversorgungs-unternehmen	Akteur repräsentiert Einrichtungen touristischer Infra- und Suprastruktur	Akteur repräsentiert landwirtschaftliche Betriebe eines Proxels	Akteur repräsentiert wasserintensive Industriebetriebe	Akteur repräsentiert Haushalte eines Proxels
Typen / Anzahl	5 Typen: Sinus-Milieugruppen 9210 bewohnte Proxel * 5 Typen = 46050 Akteure	2 Typen: Gemeinde-, und regionale Wasserversorger 1717 Akteure	[illegible]	[illegible] kt- [illegible] erbau, etc. [illegible] schaftlich [illegible] el = 58984	1 Typ: Industrie 1354 industriell genutzte Proxel = 1354 Akteure	10 Typen je Sinus-Milieuguppe: Anzahl Haushaltsmitglieder 9210 bewohnte Proxel * 5 Milieus * 10 Typen = 460500 Akteure
Entscheidung	Häufigkeit bestimmter Wassernutzungsarten, Kauf von Innovationen im Wasserbereich, Aktiviertheit	Maßnahmen zur Deckung ggf. auftauchender Defizite i[illegible] der Wasserversorgu[illegible]	[illegible]	[illegible] ment [illegible] ren, [illegible] von	Produz. Gütermenge, Einsatzmengen an Produktionsfaktoren, Änderungen an Produktionstechnologie	Migration

DeepHousehold (Umweltpsychologie)
Akteur repräsentiert Haushalte eines Proxels
5 Typen: Sinus-Milieugruppen 9210 bewohnte Proxel * 5 Typen = 46050 Akteure
Häufigkeit bestimmter Wassernutzungsarten, Kauf von Innovationen im Wasserbereich, Aktiviertheit

The Sinus-Milieus®: Social status and basic values



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Workflow

Scenario for climate change and society development

Integrative simulation

Result data, processing and analysis

Climate and Society Scenarios

Choice 1: Climate Trend	Choice 2: Climate Variant	Choice 3: Society Scenario	Choice 4: Particular Action
IPCC regional	*Baseline*	*Baseline*	*Action 1*
REMO regional	*5 warm winters*	*Performance*	*Action 2*
MM5 regional	*5 hot summers*	*Public Welfare*	*Action ...*
Extrapolation	*5 arid years*		
	REMO scaled & bias corrected		
	MM5 scaled & bias corrected		

The Society Scenarios

Baseline

- Continuation of the Status Quo
- Business as usual

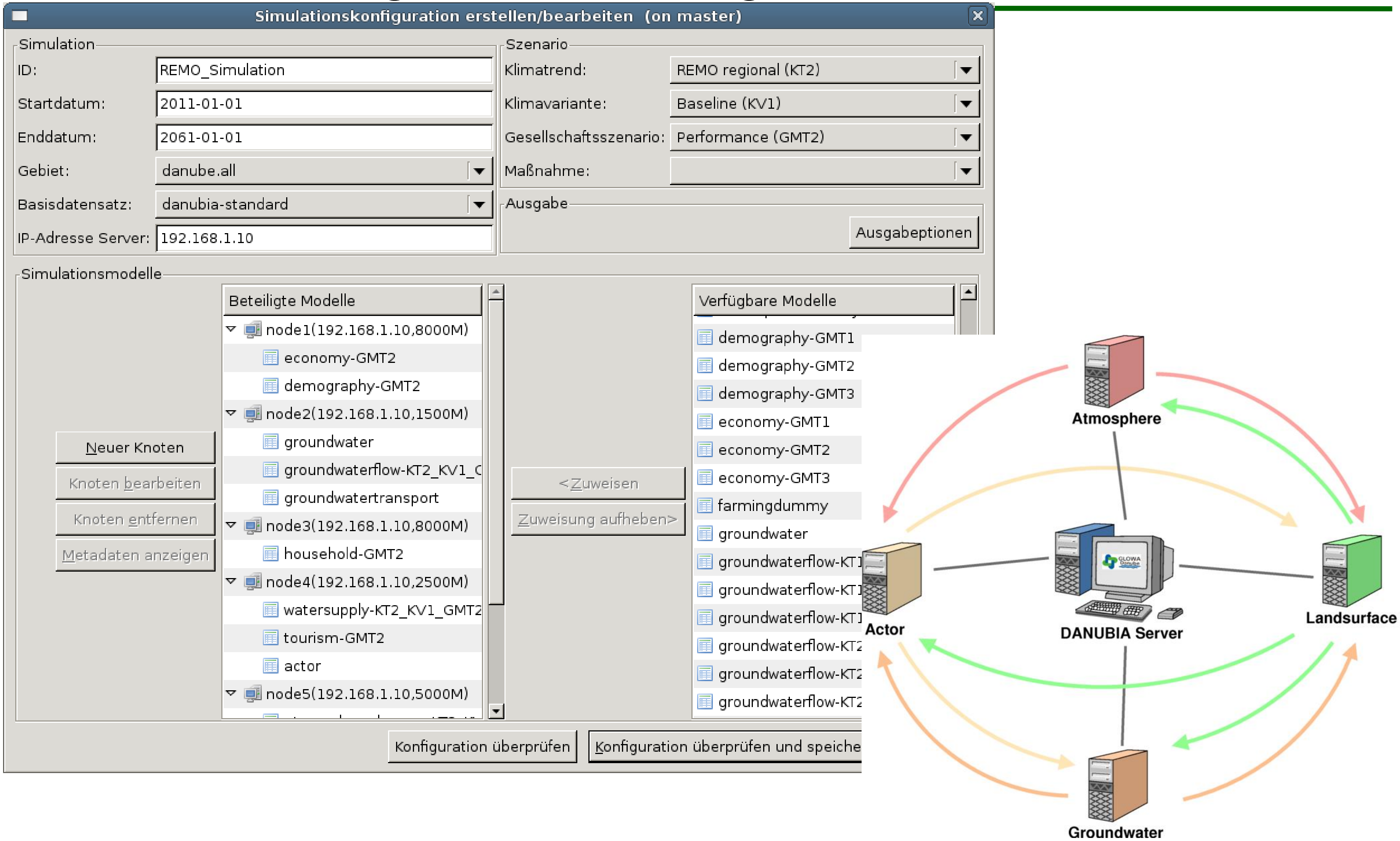
Performance

- Liberalization of the markets
- Collective responsibility looses influence
- Individuals have to care for themselves

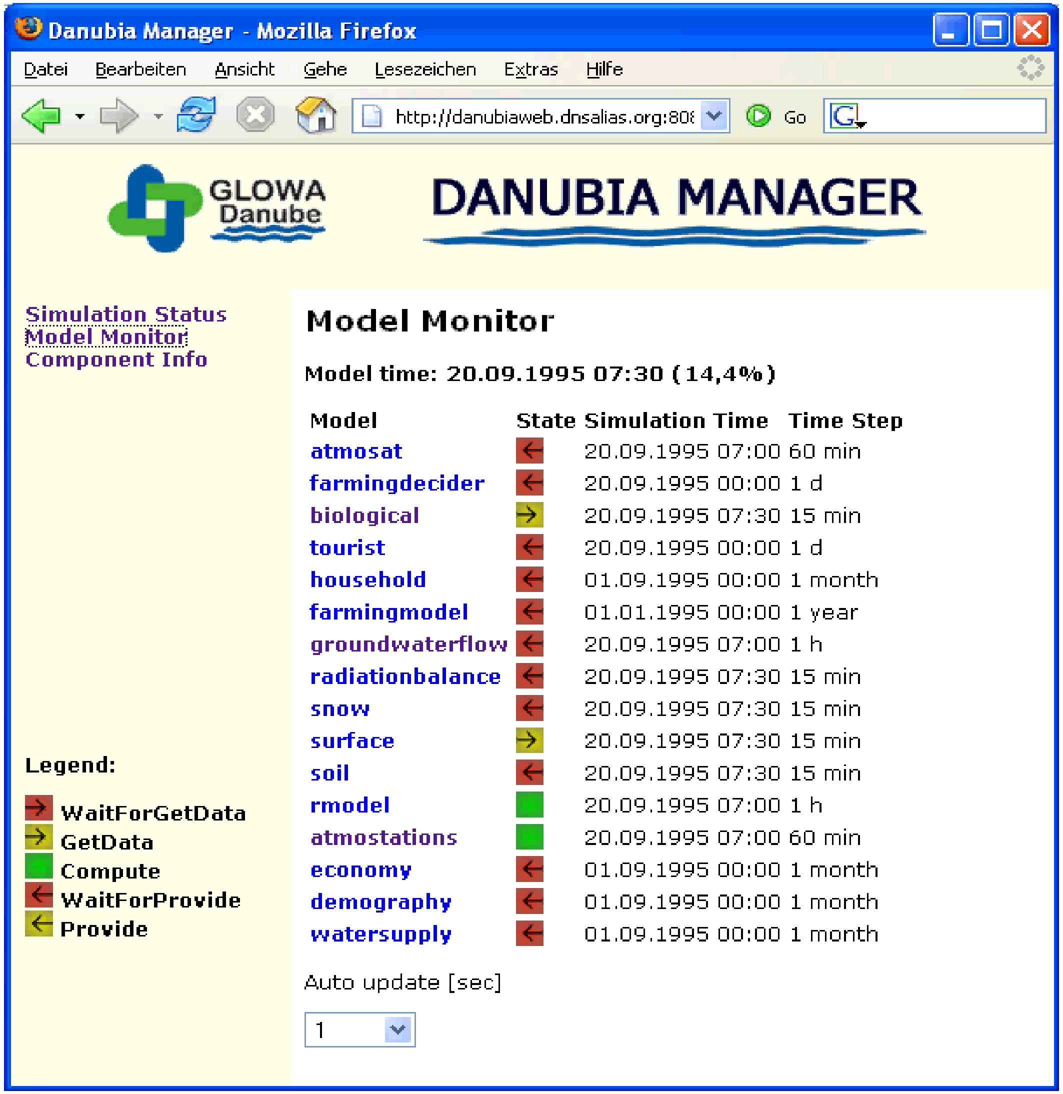
Public Welfare

- Policy and economy are oriented towards common welfare
- Societal responsibility for social and environmental issues
- Social justice and equal opportunities

Configuration of Integrative Simulations



Monitoring of a Running Simulation



Results for the Upper Danube Basin (2011 – 2060)

- Used Climate Scenario (IPCC):
  temperature increase 3.3°C – 5.2°C between 1990 and 2090.
- Trends for precipitation:
  More rainfall in winter, less in summer (-3.5% to -16.4% per year)
- Consequences:
  - Reduction of water power production
  - Possible restrictions for ship traffic in summer due to low water levels
  - 30 – 60 days less snow cover per year in lower alpine regions due to temperature increase but possible improvements in high-level alpine regions
  - Less winter tourism but moderate increase of summer tourism
- Further results
  - Less private water use expected (around 20%) due to changing behaviours and new technologies (for saving water)
  - No expected shortage of drinking water, but the need for temporary adaptation strategies of water suppliers is likely (e.g. more cooperation and networks)
  - (Almost) all glaciers in the Upper Danube catchment will vanish until 2045

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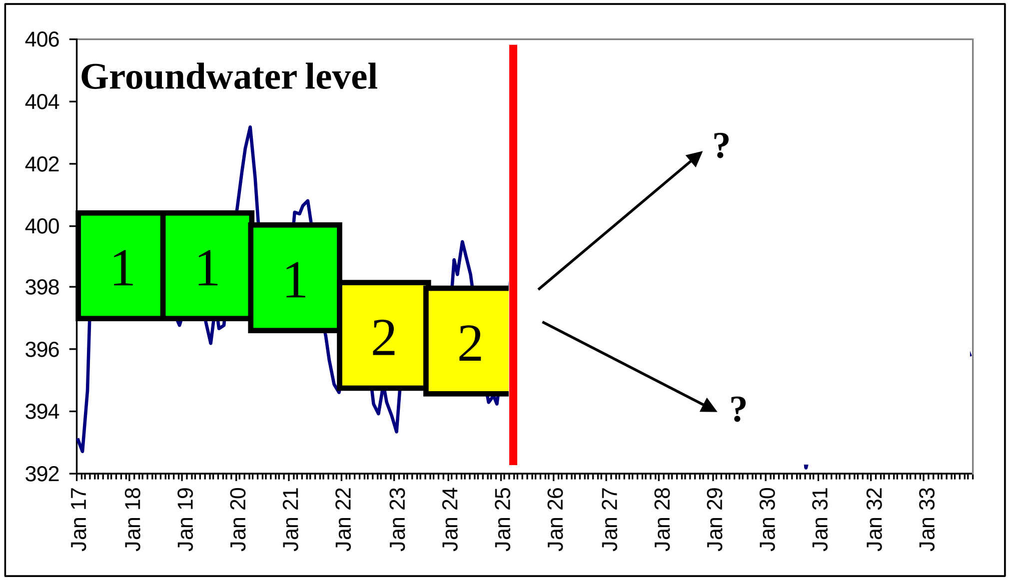
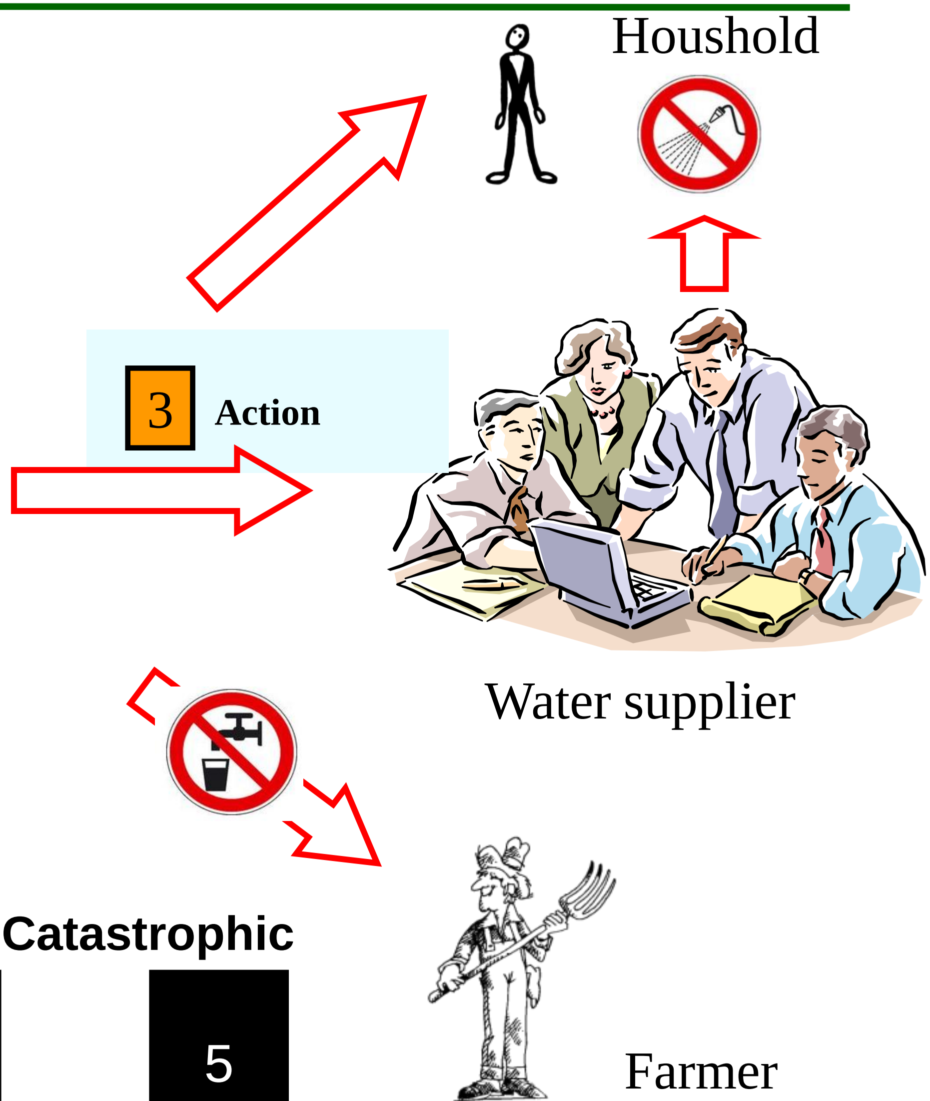
Example for Interaction Nature - Actors



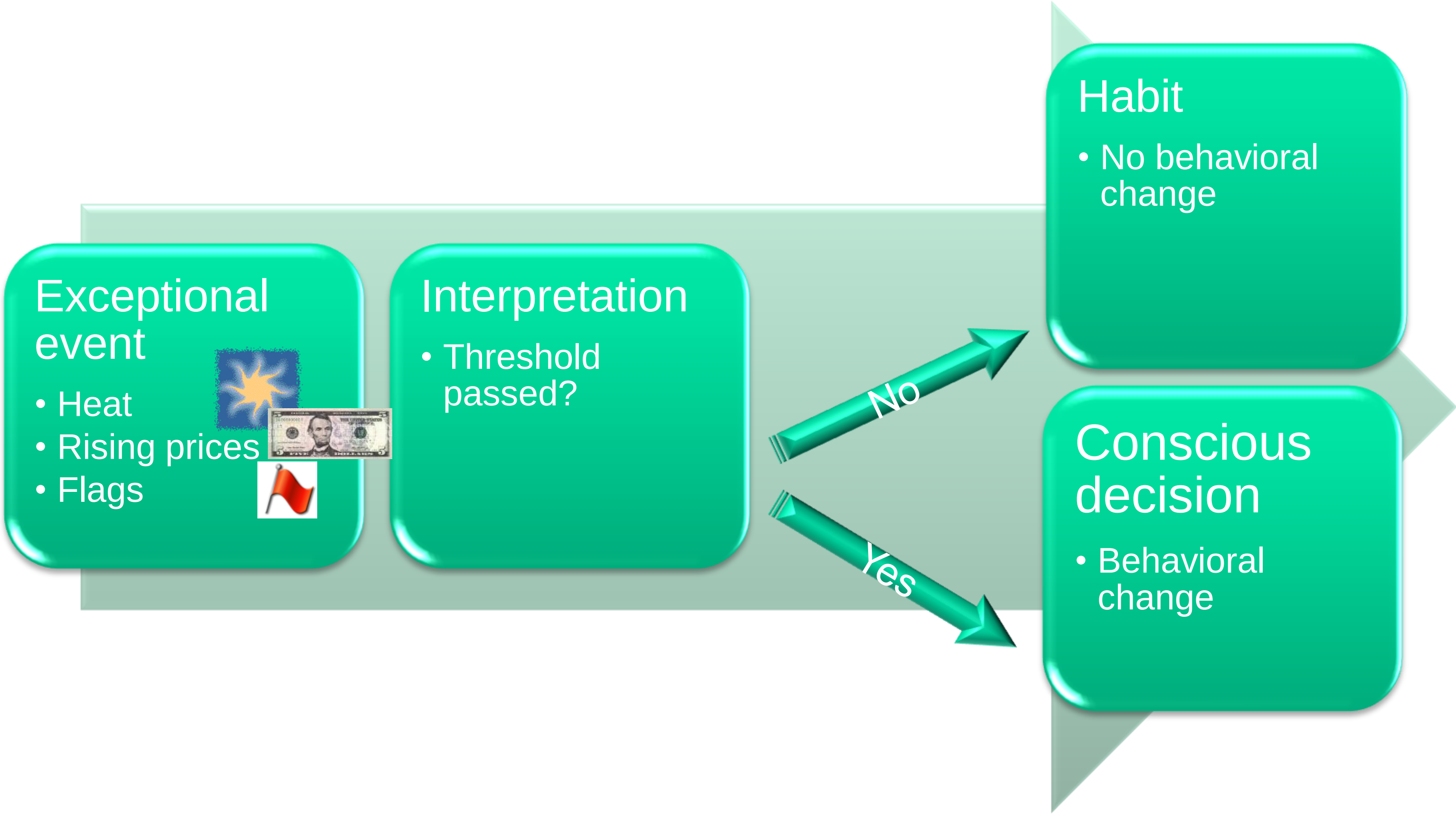


Everything ok → Critical → Catastrophic

1 2 3 4 5

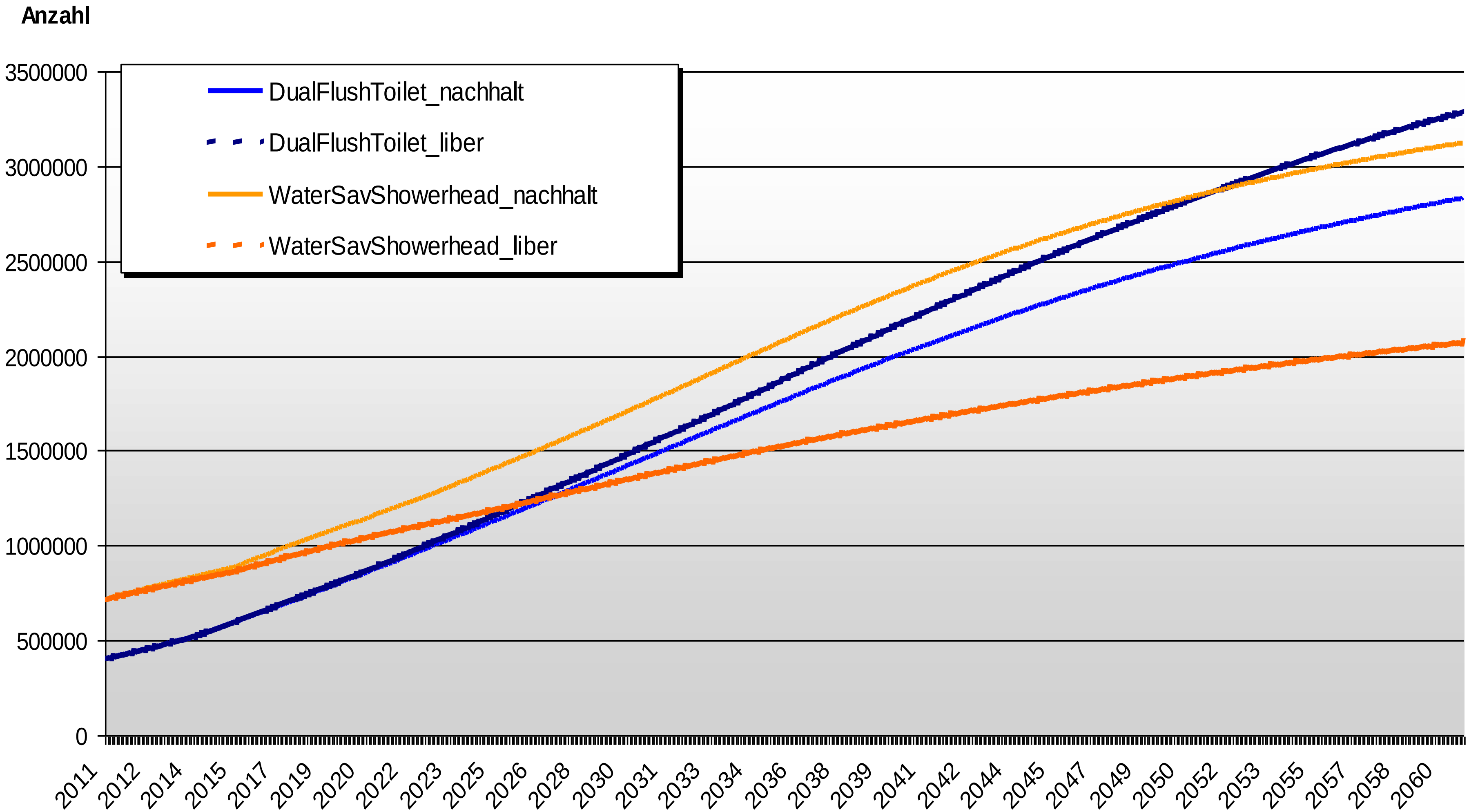
Housholds: Domestic Water Use

- 10 water uses (shower, bath, toilet, washing machine, rain harvesting, etc.)
- Habits and reactions to exceptional events

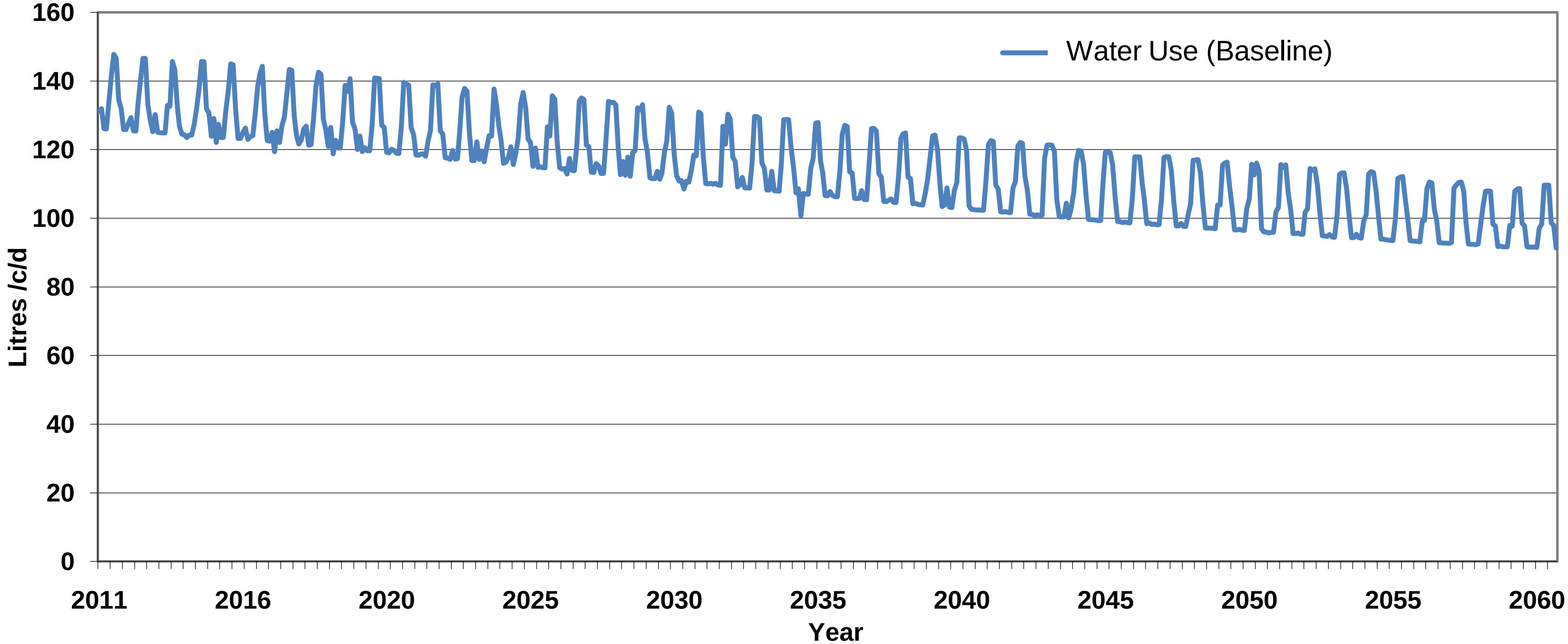


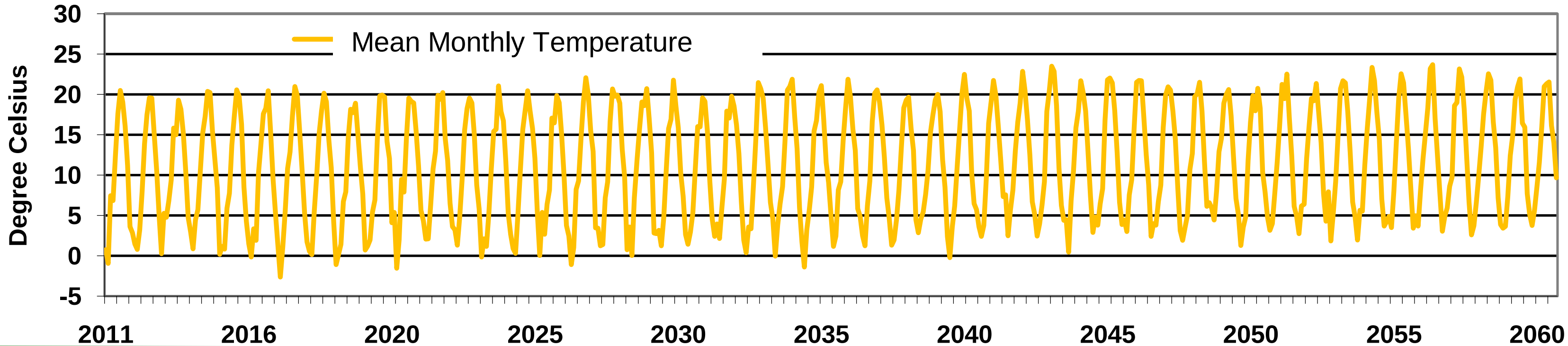
(Ernst, Schulz, Schwarz & Janisch, 2008)

Spread of Water-Saving Innovations



Diffusion of water saving technologies reduces water use





Conclusion

- Well-known methods of Informatics like **abstraction, structuring**, and **separation of concerns** can be very useful for the **conceptual integration** in multi-disciplinary projects.
- As a tool for communication the use of a **common graphical modelling language** (UML) has been proven to be very valuable**:**
  - more precision in discussions between scientists of different disciplines,
  - common understanding of the integrative aspects
- With the help of **formal methods** the **correctness** of the temporal coordination (being the heart of the whole system) could be verified.
- Framework technology
  - **supports model developers** to develop and integrate their simulation models into the overall system structure
  - implements **general rules** (templates) which support the reliability of the system
  - applicable to **any kind of integrative simulation** which simulates spatially distributed processes with a discrete time scale.
- Next step: **Open Source DANUBIA** project for the Simulation Framework (and particular simulation models)