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Representing dynamic networks of water flow in space, time and structure using process libraries

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In 2008, Buytaert et al. asked: "Why can't we do better than TOPMODEL?" Their answer based on the development of a new generation of hydrological modelling tools, which should be accessible, portable and, especially, modular. Such modular modelling frameworks have now been developed and are used to test hypotheses of catchment behaviour. Some of these frameworks are limited to lumped models, like FUSE, SuperFLEX and MARRMoT, or allow the construction of semi-distributed models like RAVEN. Lumped and semi-distributed models are, due to their little computational costs, great tools for exploring parametric and structural model uncertainty. However, lumped and semi-distributed models are based on the intrinsic hypothesis that the internal spatial configuration of a catchment is not relevant for the runoff processes in a catchment. This assumption of the model structure cannot be scrutinized inside of these frameworks. Modelling systems with the potential to build distributed models, representing the spatial connectivity of landscape features, are eg. SUMMA and CMF.

Our modular, open access Catchment Modelling Framework (CMF, https://philippkraft.github.io/cmf/) is implemented as a library of water fluxes along the nodes of a hydrological network across spatial and temporal scales. It facilitates building models representing current process understanding. It is written in C++ as a library of the Python programming language and is supported and constantly extended since 2009. Due to the open nature, models build with CMF can be adopted to data structure and qualitative expert knowledge. The CMF library contains classical equations of water flux from the Nash-Box to the Richard's equation. Often neglected anthropogenic infrastructures and activities like sewage water plants, reservoirs, irrigation and pumping can be represented with user-supplied functions. As a library, the connection to other model domains is possible, e.g. plant growth or soil chemistry models, where CMF acts as a water and solute transport module and other models as dynamic boundary conditions.

We will illustrate the use of the library concept with some applications:

- Plot scale (10^0 m²): Macropore solute transport
- Field scale (10^2 m²): Feedback loops between CO2 effect in crops and soil water availability
- Hillslope (10^4 m²): Integrated nitrogen turnover and transport model
- Riparian zone of a continental stream (10^7 m²): A distributed groundwater model to predict

plant species habitats under climate change

- Catchment (10^8 m²): Spatial explicit risk assessment of open water bodies to pesticide spray drift
- Catchment (10^9 m²): Incremental break down of a lumped model