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Physics Informed Machine Learning of Rainfall-Runoff Processes

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Modelling of rainfall-runoff phenomenon continues to be a challenging task at hand of hydrologists as the underlying processes are highly nonlinear, dynamic and interdependent. Numerous modelling strategies like empirical, conceptual, physically based, data driven, are used to develop rainfall-runoff models as no model type can be considered to be universally pertinent for a wide range of problems. Latest literature review emphasizes that the crucial step of hydrological model selection is often subjective and is based on legacy. As the research outcome depends on model choice, there is a necessity to automate the process of model evolution, evaluation and selection based on research objectives, temporal and spatial characteristics of available data and catchment properties. Therefore, this study proposes a novel automated model building algorithm relying on machine learning technique Genetic Programming (GP).

State of art GP applications in rainfall-runoff modelling as yet used the algorithm as a short-term forecasting tool which produces an expected future time series very much alike to neural networks application. Such simplistic applications of data driven black-box machine learning techniques may lead to development of accurate yet meaningless models which do not satisfy basic hydrological insights and may have severe difficulties with interpretation. Concurrently, it should be admitted that there is a vast amount of knowledge and understanding of physical processes that should not just be thrown away. Thus, we strongly believe that the most suitable way forward is to couple the already existing body of knowledge with machine learning techniques in a guided manner to enhance the meaningfulness and interpretability of the induced models.

In this suggested algorithm the domain knowledge is introduced through the incorporation of process knowledge by adding model building blocks from prevailing rainfall-runoff modelling frameworks into the GP function set. Presently, the function set library consists with Sugawara TANK model functions, generic components of two flexible rainfall-runoff modelling frameworks (FUSE and SUPERFLEX) and model equations of 46 existing hydrological models (MARRMoT). Nevertheless, perhaps more importantly, the algorithm is readily integratable with any other internal coherence building blocks. This approach contrasts from rest of machine learning applications in rainfall-runoff modelling as it not only produces the runoff predictions but develops a physically meaningful hydrological model which helps the hydrologist to better understand the catchment dynamics. The proposed algorithm considers the model space and automatically identifies the appropriate model configurations for a catchment of interest by optimizing user-defined learning objectives in a multi-objective optimization framework. The model induction capabilities of the proposed algorithm have been evaluated on the Blackwater

River basin, Alabama, United States. The model configurations evolved through the model-building algorithm are compatible with the fieldwork investigations and previously reported research findings.