Technische Universität Dresden

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Outstanding Student & PhD candidate Presentation contest

A Graph-Theoretic Framework for the Systematic Representation and Generation of Conceptual Hydrological Model Structures

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Short Summary

- From selecting models to sampling model structures
- Conceptual hydrological models can be represented as directed graphs and transformed into runnable models
- Model structures can systematically generated and sampled
- Structural uncertainty becomes a testable hypothesis space

Motivation

- Hydrological predictions depend strongly on model structure
- Model selection mostly driven by „legacy, rather than adequacy“
- Structural uncertainty is rarely treated explicitly and equifinality is omnipresent → systematic analysis requires formalization of model structures

Research Objective:
Enable systematic sampling and evaluation of hydrological model structures through a formalized and unified representation

Outlook

Next steps

- Benchmarking with more efficient recursive model generator (incidence based)
- Testing larger and more complex model structure spaces

Vision

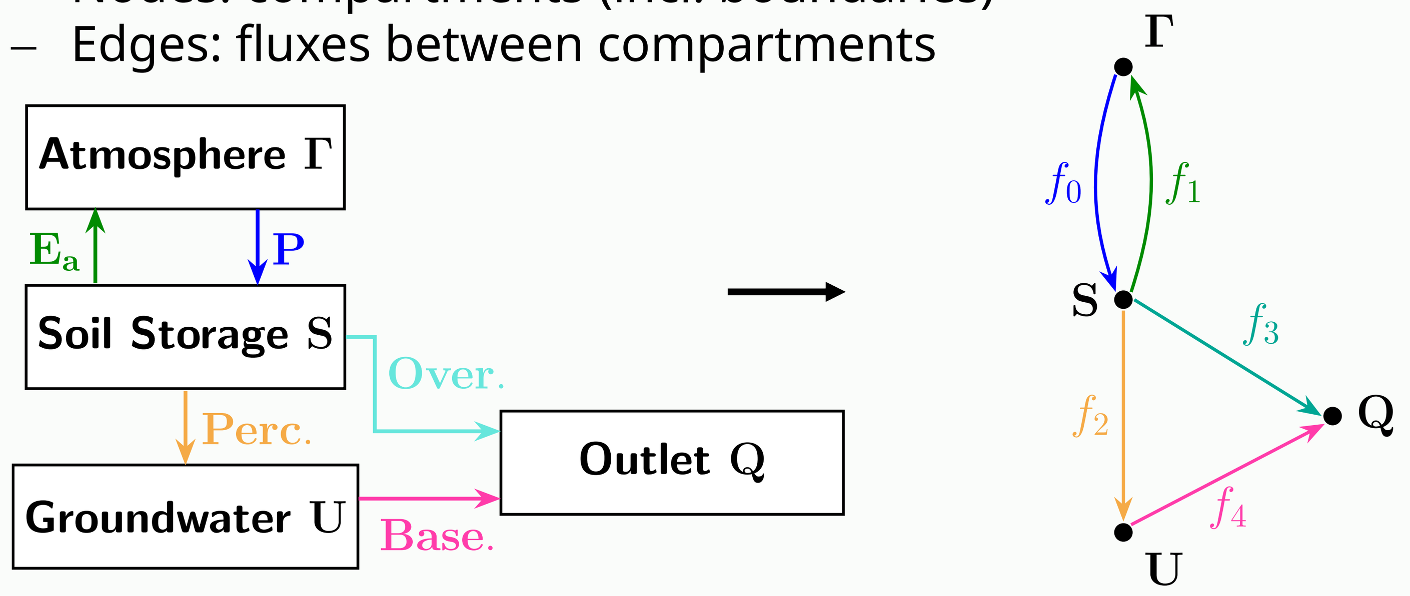
- From ad hoc model choice to **systematic structure exploration** (hypothesis testing)
- From implicit assumptions to **explicit structural uncertainty**
- **Data-driven identification** of the most suitable model structures

Core Idea

1 Representation

Conceptual hydrological models can be represented as directed graphs

- Nodes: compartments (incl. boundaries)
- Edges: fluxes between compartments



2 Formalization

Graph structures can be encoded algebraically

Adjacency matrix A

- Encodes connectivity of compartments and direction of fluxes
- Defines model topology (structure)

from \ to	Γ	S	U	Q
Γ	0	1	0	0
S	1	0	1	1
U	0	0	0	1
Q	0	0	0	0

Incidence matrix B

- Encodes node-edge relationships
- Shows origin (-) and target (+) of flux f
- Enables direct derivation of model ODE system

	f_0	f_1	f_2	f_3	f_4
Γ	-1	1	0	0	0
S	1	-1	-1	-1	0
U	0	0	1	0	-1
Q	0	0	0	1	1

3 Consequence

Graph-based encoding enables:

- Systematic generation of model strucutres
- Formal search and hypothesis testing
- Direct translation into runnable models (e.g. with RAVEN)

Model Generator

From graphs to automatic sampling of structure spaces

I Define Structure Space

- Maximum Graph
- All possible connections

	Γ	S	U	Q
Γ	0	1	0	0
S	2	0	2	1
U	0	0	0	3
Q	0	0	0	0

2 percolation methods → [linear, power-law]
2 evaporation methods → [HBV, VIC]
3 baseflow methods → [constant, linear, power-law]

Adjacency matrix with process indices

II Generate Structures

- Constrained matrix permutation enumerates candidate structures

III Filter Structures

- Overproduce and select

Topology Rules
(physical plausibility)

0	1	0	0
0	0	0	1
0	0	0	1
0	0	0	0

No *magic wells*

0	1	0	0
0	0	1	1
0	0	0	0
0	0	0	0

No *dead ends*

0	1	0	0	0
0	0	0	0	1
0	0	0	1	0
0	0	1	0	0
0	0	0	0	0

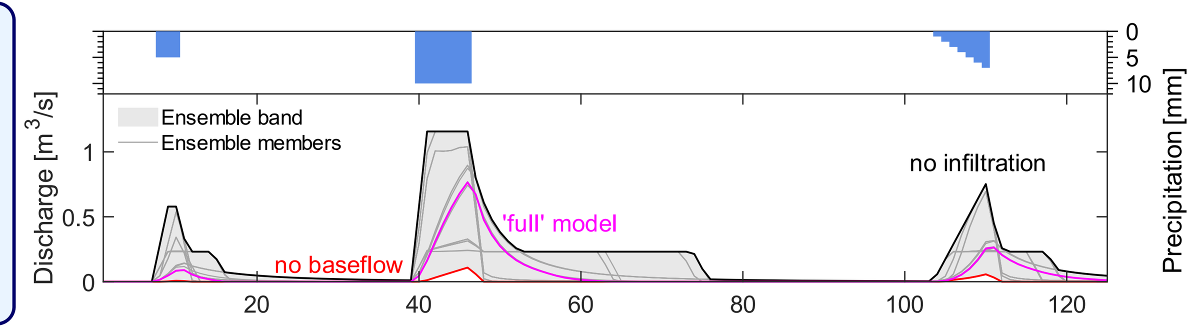
No *sub-models*

Semantic Rules
(user-defined constraints - e.g. „my models require a flux from soil to surface water (direct runoff)“

	Γ	S	U	Q
Γ	0	1	0	0
S	1	0	1	1 ✓
U	0	0	0	1
Q	0	0	0	0

IV Execute & Analyse

- Automatic translation into runnable RAVEN models
- Post hoc analysis



V Answer Key Questions

How many structures are feasible? Which ones explain the data best? What characterizes them? Are they *unique*?

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Die TUD ist Gründungspartnerin der Forschungsallianz DRESDEN-concept e.V.

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