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Simulation of flow patterns in soils

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Introduction

Motivation

- Water flow through soil is hardly predictable.
- Influences groundwater quality
- Is often studied via dye tracer infiltration (Figure 1)
- Realistic process models need not produce realistic images.

Goals

- Simulation of stained patterns in a 3D cellular automaton
- Different indices to compare real and simulated images
- Large ensembles of images for a reliable statistical analysis

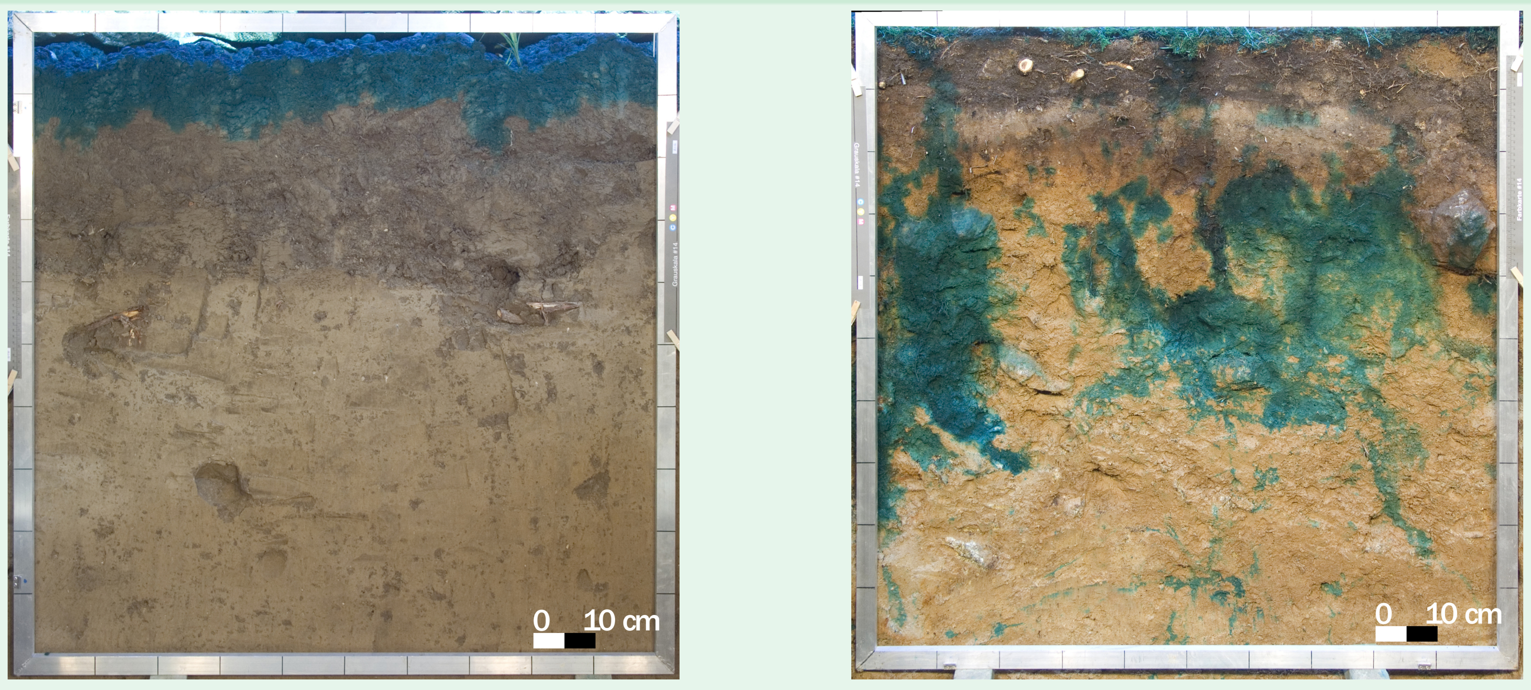
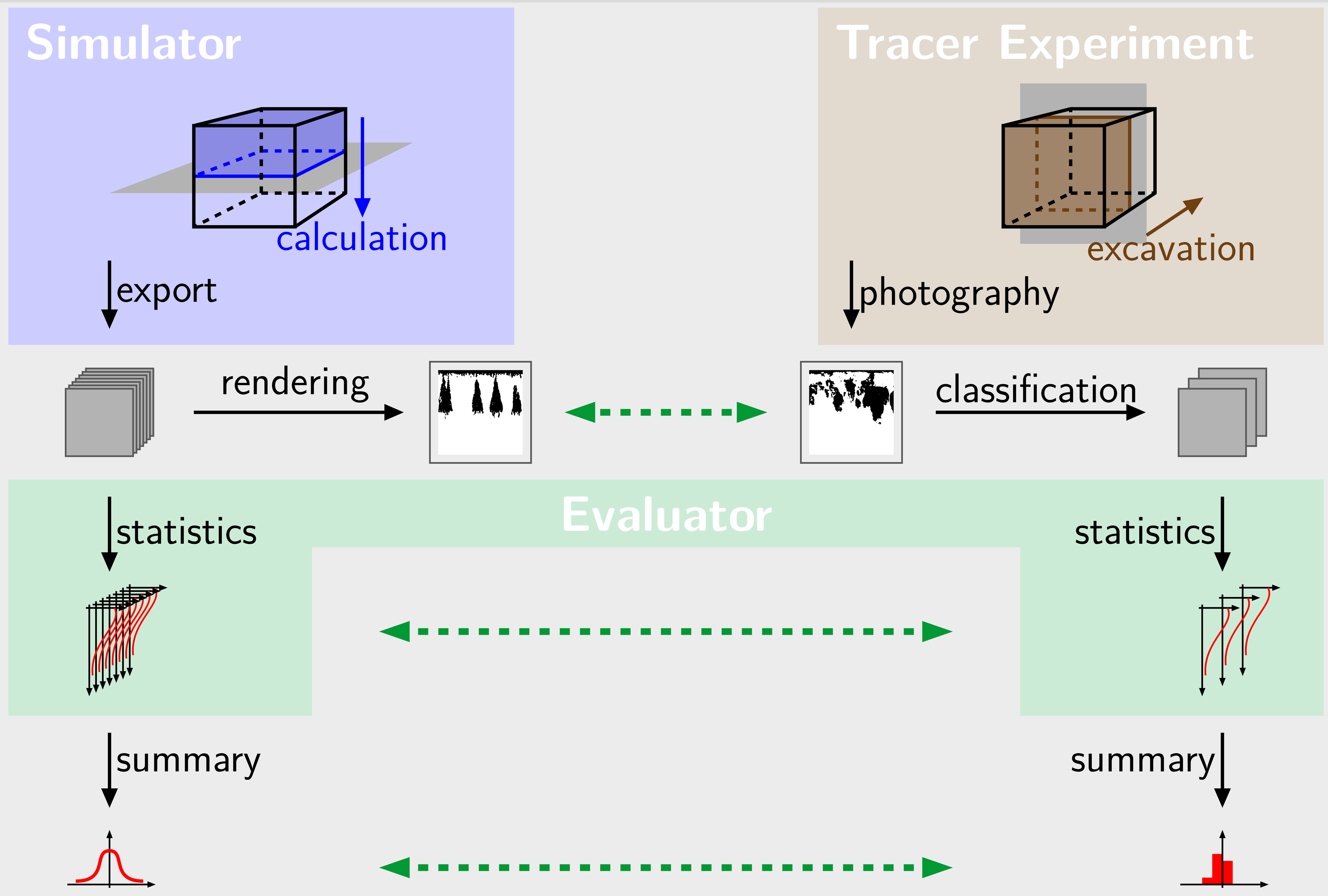


Figure 1: Brilliant Blue stained flow patterns: uniform flow (left), preferential flow (right).

Tool Design



Statistics

Desired Properties of Indices

- $0 \leq I \leq 1$
- Discriminate between uniform and preferential flow
- Detect "transition" zones
- Sensitive to connectivity

Candidate Indices

- Dye coverage P: $P = \frac{\text{number of stained pixels}}{\text{width}}$
- Metric entropy H_μ: $H_\mu = -\frac{\sum p_i \log_2 p_i}{L}$
- Connectivity C: $C = \frac{\sum (\text{run}_i)^2}{(\sum \text{run}_i)^2}$

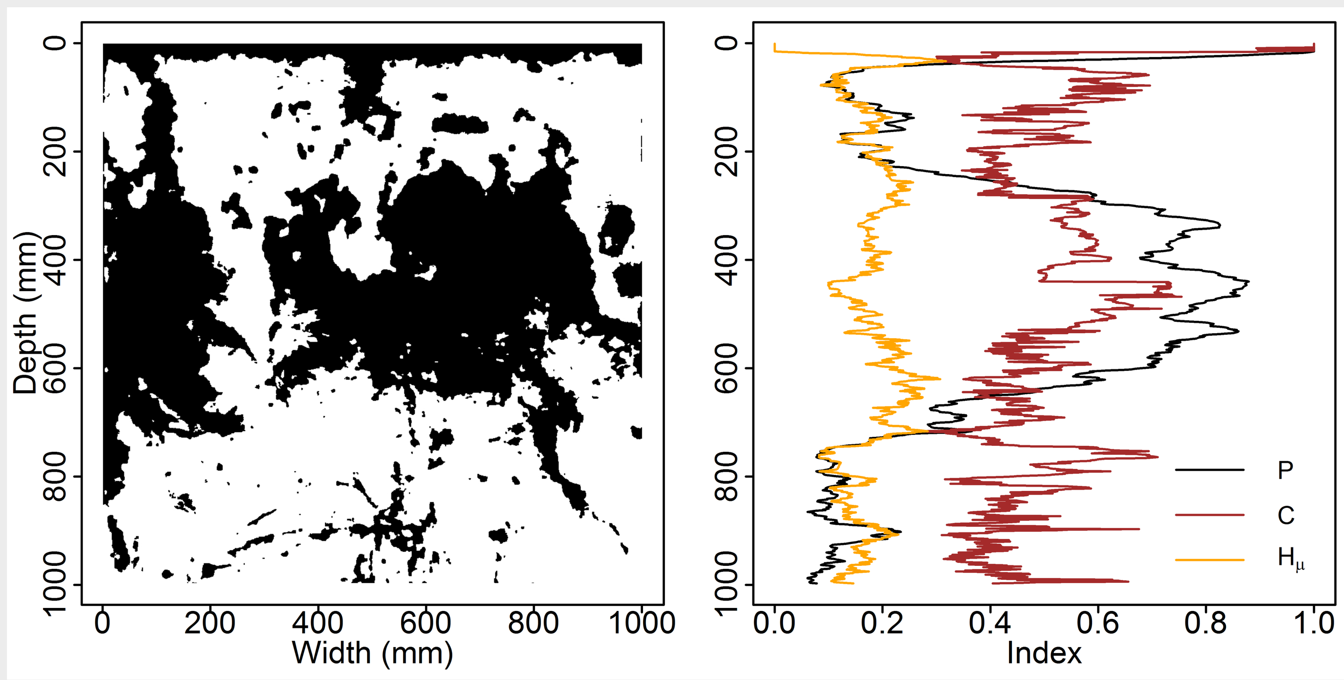


Figure 2: Classified binary image (stained pixels are black) (left) and corresponding indices (right)

First Results

Simulated Images

- Simulation of uniform, mixed and preferential flow (Figure 3 from left to right).
- Simple local rules for probability of tracer propagation: different probabilities per horizon, vertical and horizontal gradients.

Choice of Indices

- Dye coverage reflects overall staining, discriminates little between uniform and preferential flow.
- Metric entropy detects "transition" zones between uniform and preferential flow.
- Connectivity is sensitive to connected regions, does not distinguish between uniform and preferential flow.

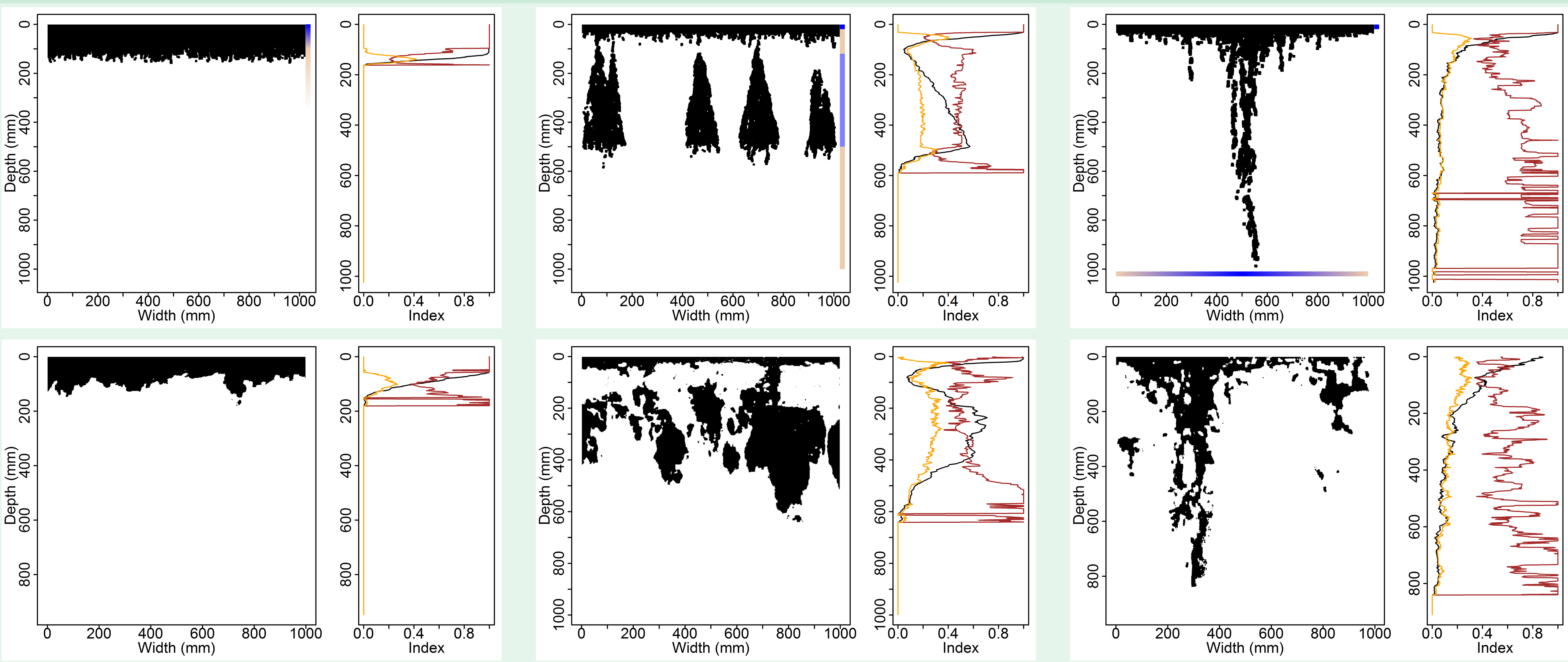


Figure 3: Simulated (top) and real (bottom) images and their indices (P (black), C (brown) and H_μ (orange)). The coloured bars in the simulated images show the probability of tracer propagation: blue is high probability and brown is low probability. Vertical and horizontal bars indicate that probability rules vary vertically and horizontally, respectively. Left: upper horizon with increasing vertical gradient (20–100 mm) and a lower horizon with decreasing vertical gradient (20–350 mm). Center: alternating horizons with high and low probabilities. Right: upper horizons with high probability (0–20 mm) and a lower horizon with a horizontal probability gradient with highest probability at 500 mm.

Conclusions

- Simple local rules in a 3D cellular automaton produce realistic flow patterns.
- Dye coverage, metric entropy and connectivity are sensitive to different features in images.
- Thus, they and their combinations might be informative for image analysis.

Outlook

Simulation Tool

- Add conservation of mass to allow for
- Simulation of dye concentration maps

External Data

- Simulation of hydraulic conductivity (via RandomFields [2] in R [1])
- Incorporation of roots and fissures

References

[1] R Development Core Team. *R: A Language and Environment for Statistical Computing.* ISBN 3-900051-07-0. R Foundation for Statistical Computing. Vienna, Austria, 2010. URL: http://www.R-project.org.

[2] M. Schlather. *RandomFields: Simulation and Analysis of Random Fields.* R package version 1.3.41. 2009. URL: http://CRAN.R-project.org/package=RandomFields.

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