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Image processing for studying size segregation in bedload transport: detection and tracking

Hugo Lafaye de Micheaux, Christophe Ducottet, Philippe Frey

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1. Context and objectives

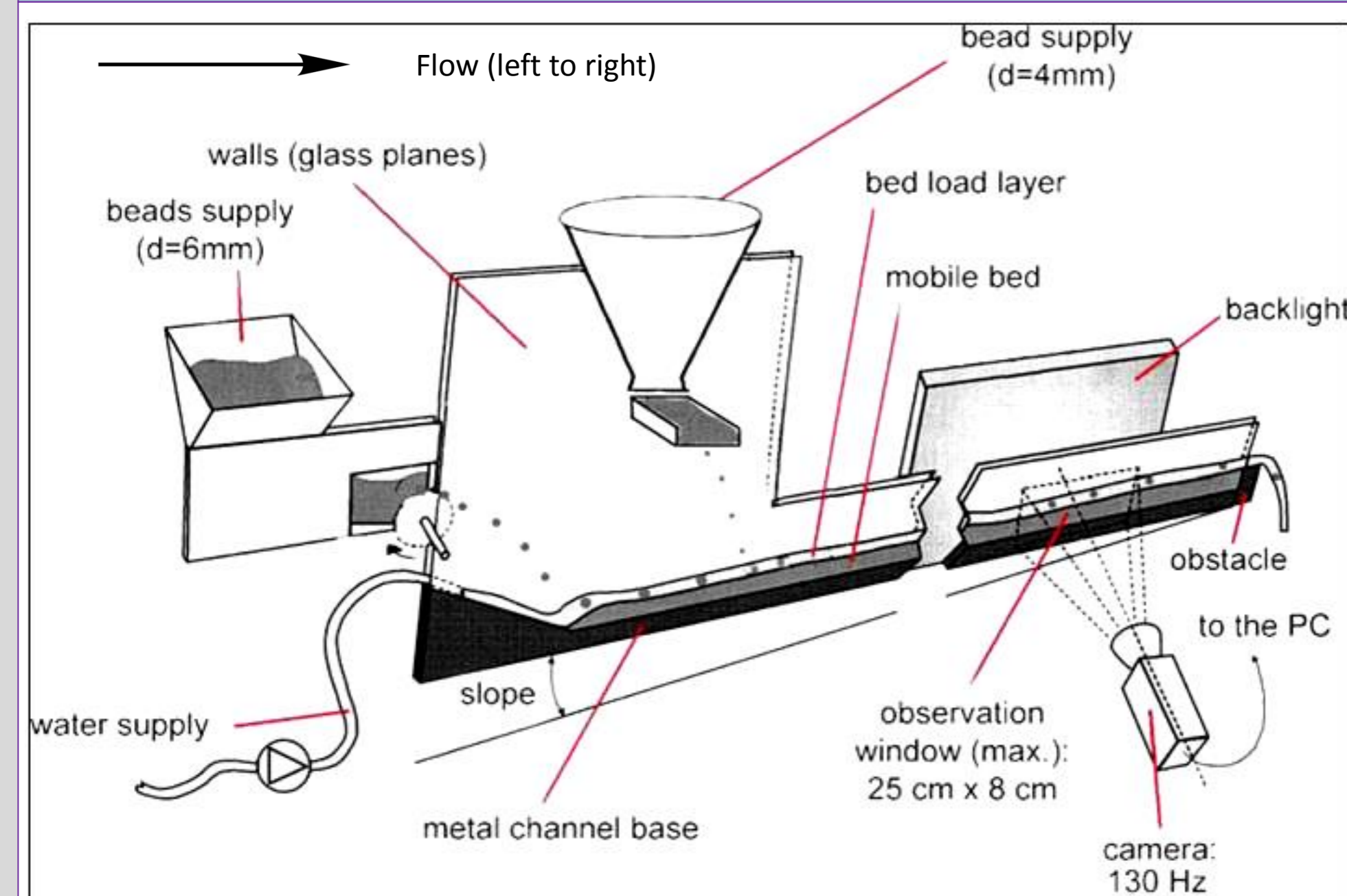
Global aim: studying bedload transport thanks to experiments with two-size beads in a water flow.

Main objective: track beads over long time sequences to better understand size segregation responsible for complex morphology structures.

The idea: propose an **online particle filter-based tracking algorithm** (framework from [2])

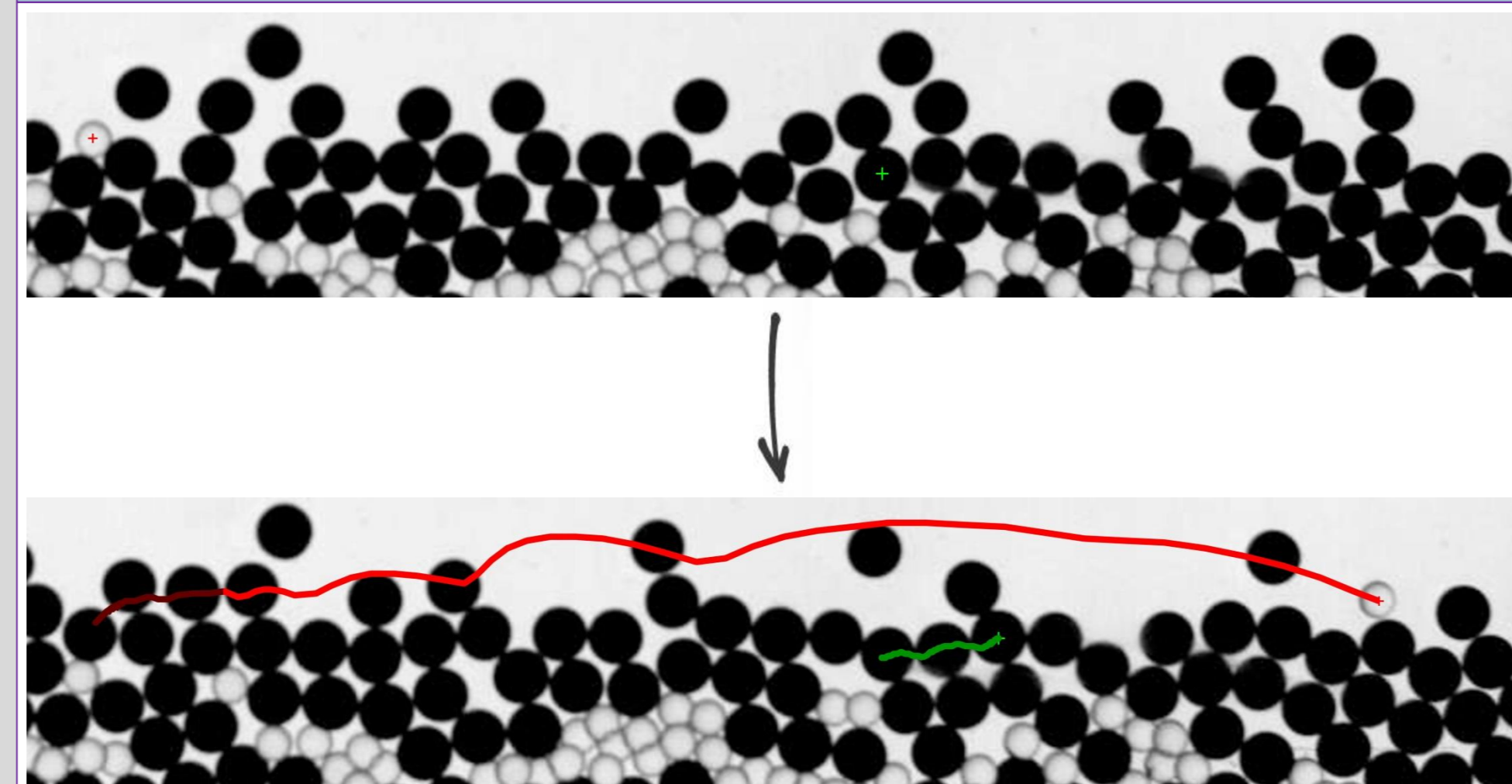
1. Include **adapted multiple motion models** with known mechanical dynamics to anticipate bead locations.
2. Introduce an observation model from a conditional likelihood to handle detection errors.

2a. Experimental setup



Experimental arrangement sketch (modified from [1])

2b. Tracking & bedload transport



Example of 2 trajectories from the experiment

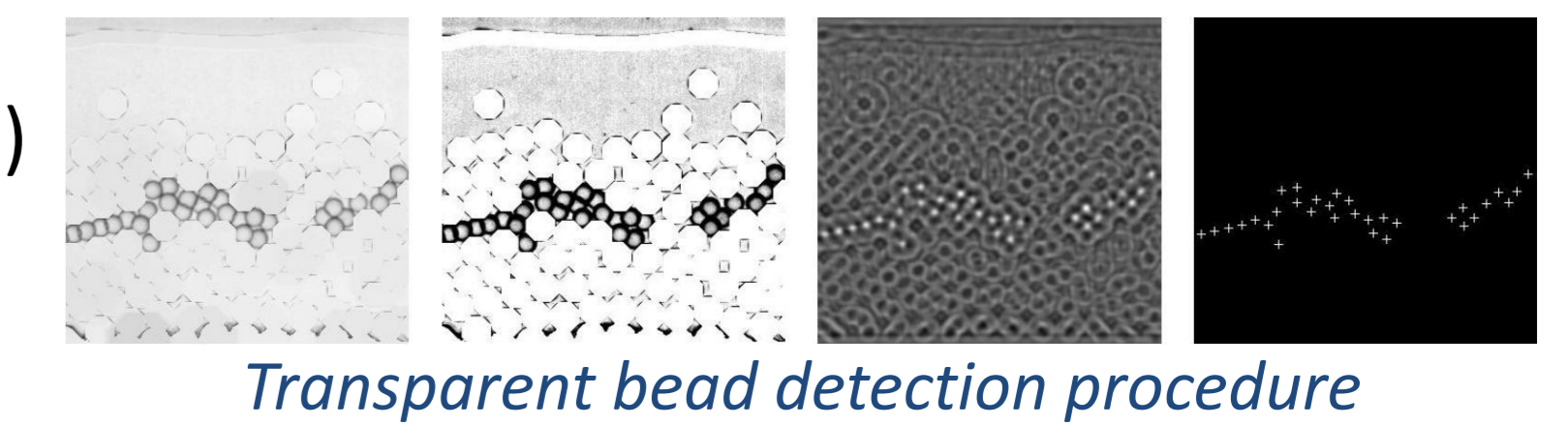
Tracking bedload sediment transport to study:

- Velocities, concentrations, bedload granular rheology
- Size segregation and associated morphology

3. Multi-model tracking algorithm [3]

Stage 1: Object detector

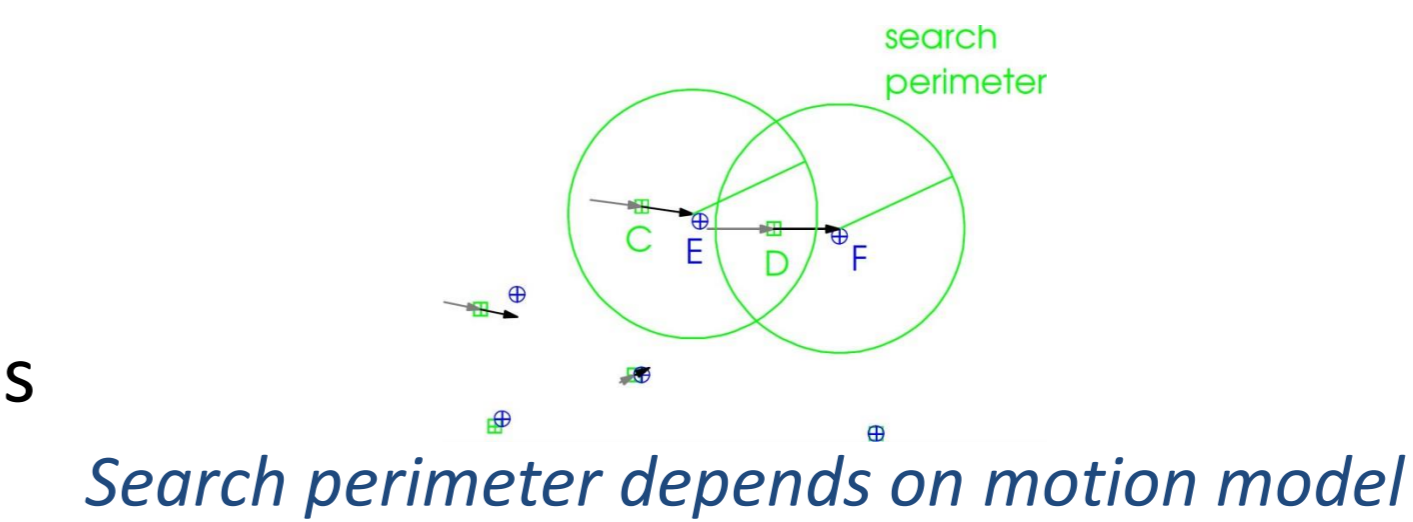
- Use specific morphological operations (erosion, hconvex, cross-corr,...)
- Measure motion states based on neighborhood and velocities
- Return observation state $z_t = \{x_t^{obs}, u_t^{obs}, s_t^{obs}\}$



Transparent bead detection procedure

Stage 2: Data association

- Perform greedy algorithm on best matching combinations



Search perimeter depends on motion model

Stage 3: Particle filtering

Objective: Estimate state $c_t = \{x_t, u_t, s_t\}$ of targets according to observations z_t
 1 target \Rightarrow cloud of N particles, 1 particle \Rightarrow 1 state $c_t^i = \{x_t^i, u_t^i, s_t^i\}$

Based on a **Sequential Monte Carlo approach (SMC)** and a **Markov Chain**:

1. **Prediction**: predict target state according to evolution model on particles

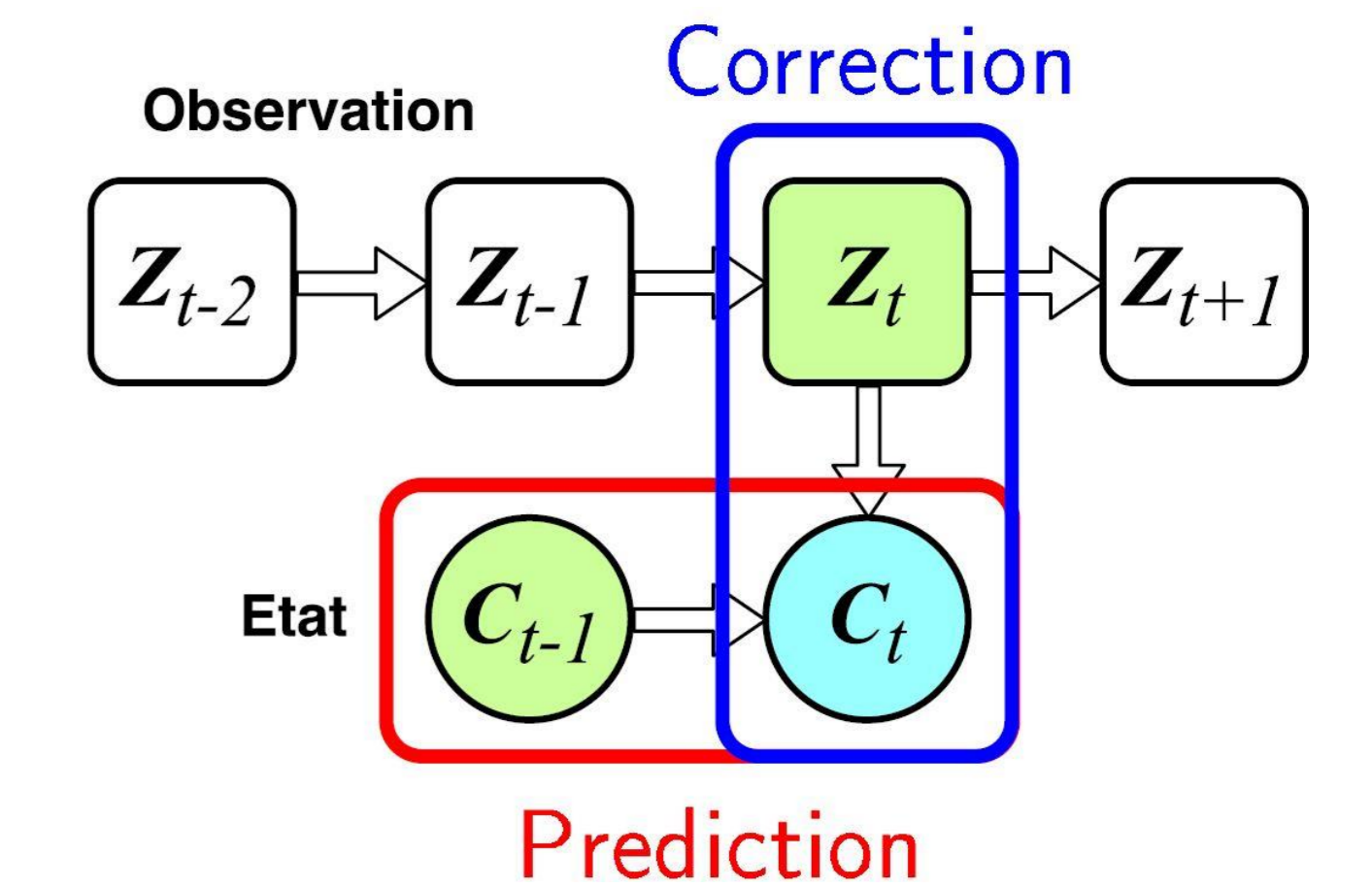
3 motion models based on bedload dynamics:

- Resting - *not moving* - $(x, y)_t = (x, y)_{t-1} + \epsilon_{rest}^{(x,y)}$
- Rolling - *sliding on others* - $(x, y)_t = (x, y)_{t-1} + (u, 0)_{t-1} \Delta t + \epsilon_{roll}^{(x,y)}$
- Saltating - *bouncing on others* - $(x, y)_t = (x, y)_{t-1} + (u, v)_{t-1} \Delta t + \epsilon_{salt}^{(x,y)}$

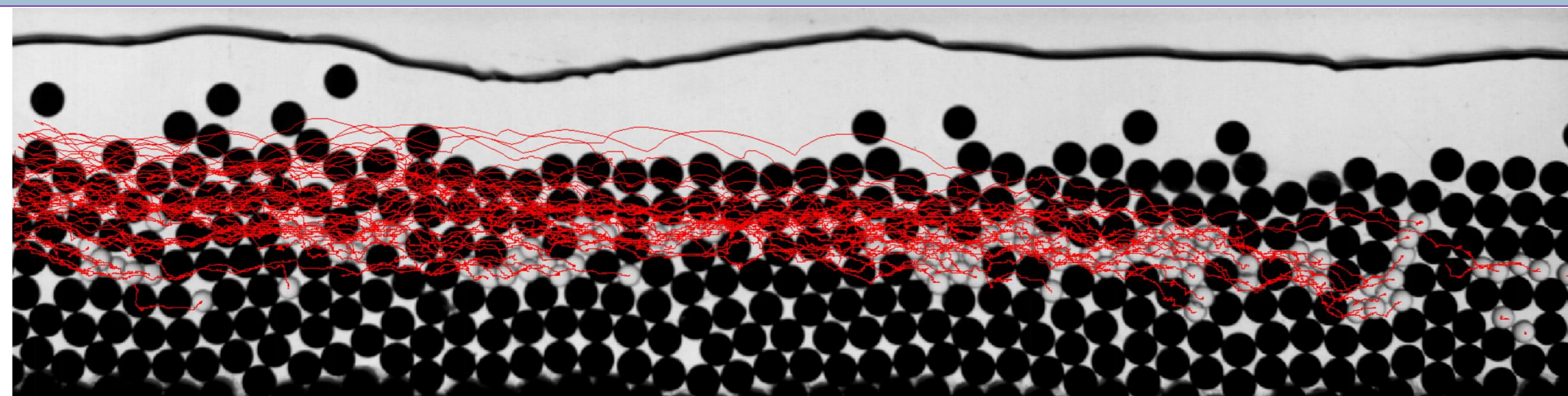
2. **Correction**: correct predicted state thanks to observations

- Particle importance weighting $w_t^i = p(z_t | c_t^i) = p(x_t^{obs} | x_t^i) \cdot p(u_t^{obs} | u_t^i) \cdot p(s_t^{obs} | s_t^i)$
- Normalize weights and resample particles

3. Final target state estimation by averaging resampled particles



4. Example of tracking results



5. Conclusions & Perspectives

➤ **New online particle filter-based tracking algorithm based on multiple dynamic models:**

- Input of object mechanical dynamics helps approaching real trajectories.
- Allows studying bedload transport with high confidence.

Perspectives : apply to long sequences of sediment transport to study high and lower frequency phenomena

References

- [1] Hergault, V., Frey, P., Métivier, F., Barat, C., Ducottet, C., Böhm, T. & Ancy, C. (2010). Image processing for the study of bedload transport of two-size spherical particles in a supercritical flow. *Experiments in fluids*, 49, 1095-1107.
- [2] Isard, M. & Blake, A. (1998). A mixed-state condensation tracker with automatic model-switching. *IEEE ICCV*, 107-112.
- [3] Lafaye de Micheaux, H., Ducottet, C. & Frey, P. (2018). Multi-model particle filter-based tracking with switching dynamical state to study bedload transport. *Accepted by journal Machine Vision and Applications, Springer*.

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