

# Clogging in Granular Flow through a Bottleneck

César Mejía & Marnick Huisman  
Simulation of Complex Systems (FFR120) | Friday 19-12-2025

## Introduction & Motivation

Granular flow through narrow openings is common in industry and nature, found in systems ranging from grain silos to crowd evacuations.

A key feature of these systems is **clogging**: the spontaneous formation of stable particle arches that completely block the flow. Unlike fluids, granular materials can switch between flowing and jammed states due to **collective interactions** rather than individual particle properties.

**Project Goal:** We investigate the statistics of clogging by combining:

- **Molecular Dynamics (MD):** To model realistic physical forces.
- **Cellular Automata (CA):** To explore parameters rapidly.

We focus on how jamming probability depends on:

- Orifice width  $D$
- Friction coefficient  $\mu$
- Stochastic effects (noise)

## Methodology: Molecular Dynamics

We simulate a two-dimensional silo containing  $N = 200$  circular discs under gravity using a Discrete Element Method. Particle motion follows Newton's equations:

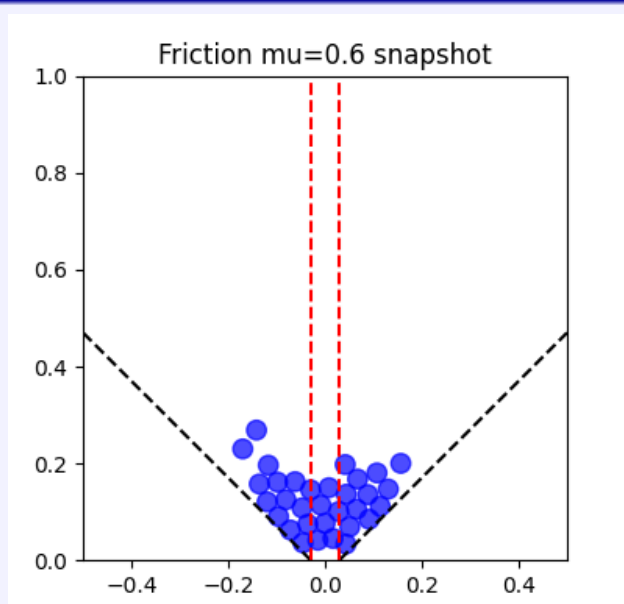
$$m\ddot{\mathbf{r}}_i = m\mathbf{g} + \sum_j \mathbf{F}_{ij}^{\text{cont}} + \mathbf{F}_i^{\text{wall}} + \mathbf{F}_i^{\text{noise}} \quad (1)$$

### Contact physics:

- **Normal force:** Linear spring-dashpot model,  $F_n \propto \delta_{ij}$
- **Tangential force:** Coulomb friction limited by  $|F_t| \leq \mu F_n$

This combination captures elastic collisions, energy dissipation, and stick-slip behavior essential for stable arch formation.

## Visualisation: Clogged System



A jammed configuration showing a stable arch of particles at the orifice. Walls are black lines, orifice edges in red, and the arch location highlighted in blue.

## Defining a Jam

A simulation is classified as **jammed** when both conditions are satisfied:

- 1 No particles discharge for a sustained time window  $\Delta t_{\text{jam}}$
- 2 A mechanically stable arch spans the outlet

This definition avoids confusing transient slowdowns with true clogging events.

## Methodology: Cellular Automata

To complement the computational cost of MD, we implement a Cellular Automata model based on local update rules on a grid.

### The CA model:

- Ignores explicit forces and momentum
- Updates particle positions probabilistically
- Allows extremely fast parameter sweeps

Although less detailed, the CA model efficiently identifies flow-clog transitions and guides parameter selection for MD simulations.

## Results: Effect of Geometry ( $D$ )

The orifice width  $D$  is the dominant control parameter.

### 1. Small openings ( $D \leq 0.12$ ):

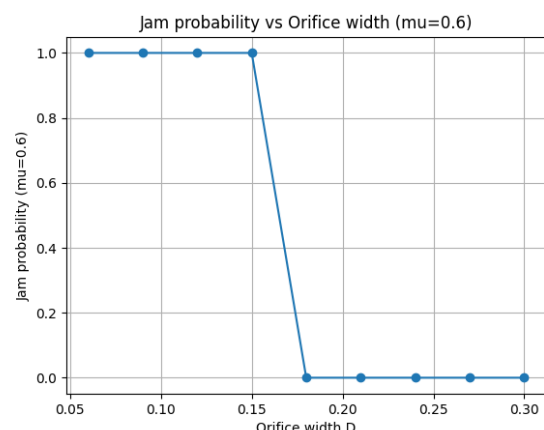
Particles are forced into a narrow funnel. Few exit configurations exist, making the formation of blocking arches highly probable. The jamming probability approaches unity.

### 2. Transition regime:

As  $D$  increases, the mean number of discharged particles grows nonlinearly and the probability of forming a spanning arch rapidly decreases.

### 3. Large openings ( $D \geq 0.18$ ):

Geometric constraints relax and the system enters a continuous flow regime where jamming becomes statistically negligible.



Jamming probability drops sharply as orifice width ( $D$ ) increases, marking a clear phase transition from clogged ( $P = 1$ ) to flowing ( $P = 0$ ) state.

## Results: Role of Friction ( $\mu$ )

While geometry determines whether an arch can span the opening, friction controls its stability.

### Intermediate openings:

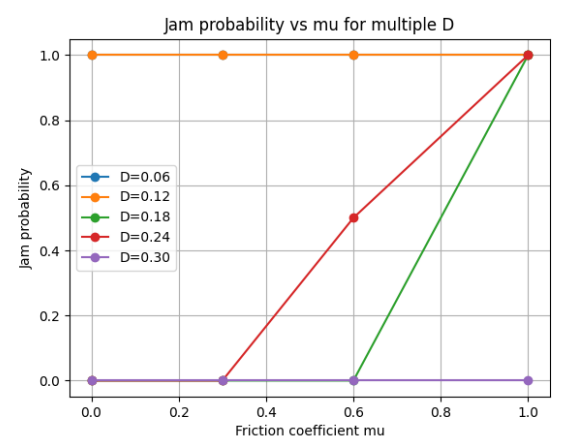
Increasing  $\mu$  significantly increases jamming probability. Friction stabilizes tangential contacts and force chains, allowing marginal arches to support the weight above them.

### Large openings:

Friction becomes ineffective once the gap is too wide for coherent arch formation.

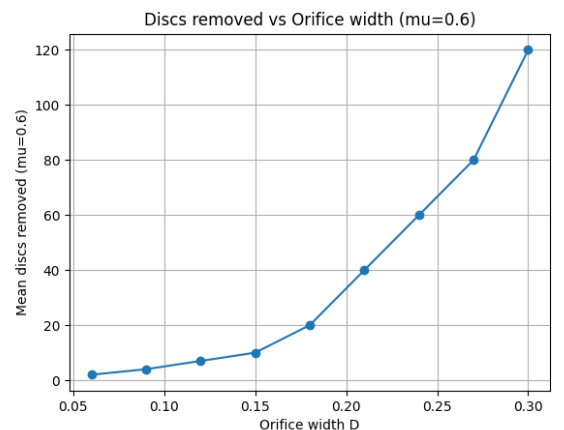
### Remaining mass:

Low friction allows efficient rearrangement and discharge, while high friction leads to rapid stabilization and mass saturation inside the silo.



Friction dominates stability at intermediate widths ( $D \approx 0.18 - 0.24$ ). High  $\mu$  stabilizes arches, whereas very small or very large widths are insensitive to friction.

## Results: Discharge Efficiency



Mean discharge count increases non-linearly with orifice width, reflecting rapid destabilization of arches for wider exits.

## Conclusion & Outlook

Clogging is a collective phenomenon driven by the combination of **geometry** and **contact mechanics**.

### Key Findings:

- **Small outlets** jam due to strict geometric constraints.
- **Intermediate outlets** jam because friction stabilizes the arches.
- **Large outlets** allow continuous flow.

We found that this transition is robust, persisting even with noise and variations in particle size.

**Future Work:** Future studies should extend this model to **three dimensions** and analyze the internal **force networks** to better understand how arches stabilize.