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Macroscopic friction from the collective slip of contacting asperities

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Abstract

Friction is well understood at the macroscopic scale as well as on the scale of individual asperities, but it is still unclear how to link the different length scales. In this work, we investigate how static friction originates from the collective slip of asperities. In our model the asperities and the bulk are represented as masses connected by springs. Numerical simulations provide no support for the intuitive notion that the onset of frictional sliding is similar to the growth of a crack between the two surfaces. Instead our model shows that the order in which the asperities start to slip as the bulk is pulled parallel to the surface is strongly dependent on the distribution of contact pressure at the asperities.

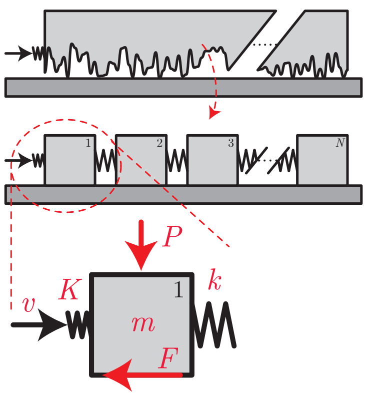

Figure 1. Schematic of the computational model. Only nearest-neighbor springs are illustrated.

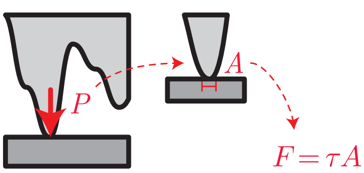

Figure 2. An asperity's height determines its area of contact and hence a block's maximum friction force.

Model

A schematic of our model is shown in **Figure 1**. The sliding body is modeled as a series of rigid blocks connected by springs. We consider two models for these internal springs: Nearest-neighbor springs with spring constant k (NN) and long-range springs (LR) with spring constant

- k between nearest neighbors,
- $k/2$ between next-nearest neighbors,
- $k/3$ between third-nearest neighbors and so on.

The first block is subjected to a prescribed displacement vt by a spring of stiffness K.

Each block feels static friction with magnitude $\leq F$ or kinetic friction with magnitude F. We do not distinguish between static and kinetic coefficients of friction.

A 'realistic' distribution of F is determined from the distribution of asperity heights. An asperity's height determines the pressure P on it when the two surfaces are brought into contact. From the pressure on an asperity its contact area A and its maximum friction force $F = \tau A$ can be derived, as illustrated in **Figure 2**.

Results

Figure 3 shows the block displacements for a dynamic and an equivalent quasistatic simulation of four blocks, with the specific combination of parameters $v = F\sqrt{mk}$ and $K = k$. These results indicate that the slip of the interface is governed by quasistatic rather than by dynamic effects.

The scaling of the number of sliding blocks for the long-range model, shown in **Figure 4**, is very sensitive to the distribution of maximum friction forces F (here linearly increasing or decreasing from the loaded edge), whereas for the model with only nearest-neighbor springs the number of sliding blocks always scales approximately as $\sqrt{vt}$.

Figure 5 shows the number of sliding blocks for such a system as a function of prescribed displacement vt for a randomly rough surface. The distribution of friction forces was determined as illustrated in **Figure 2**. The model with long-range interaction predicts linear initial growth of the number of sliding blocks.

Conclusions

- For the model under consideration, the behavior of two bodies in contact up to the moment of sliding is not governed by the collective dynamics but by the collective quasistatic slip of asperities.
- The order in which the asperities start to slip is strongly dependent on the distribution of contact pressure at the asperities.

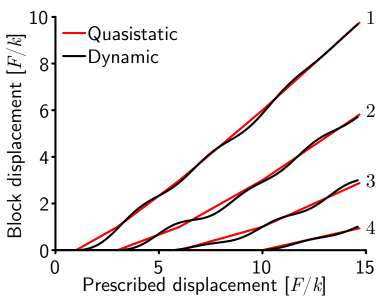

Figure 3. Consecutive slip of four blocks with only nearest-neighbor interaction and identical friction forces.

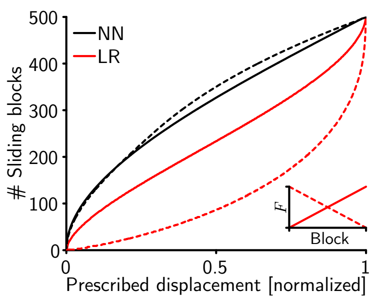

Figure 4. Maximum friction forces linearly increasing (solid lines) or decreasing (dashed lines).

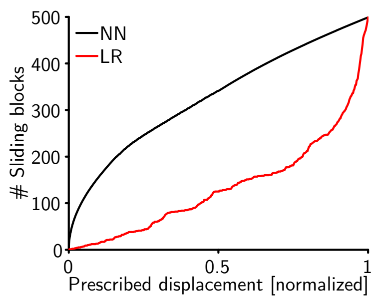

Figure 5. Consecutive slip of 500 blocks when the distribution of friction forces is determined by the asperity heights.