Microscopic prediction of stick-slip friction

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Impact. Understanding how slip at a frictional interface initiates is important for e.g. earthquake prediction and precision engineering. The force needed to start sliding a solid object over a flat surface is classically described by a "static friction coefficient": a constant established by measurements. It was recently questioned if such constant exists, as it was shown to be poorly reproducible.

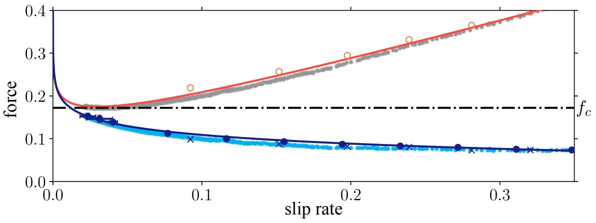
Model. A common model divides the interface in elastically interacting 'blocks' that are elastic up to a certain threshold. These thresholds are distributed as all contacts are different. Different than commonly assumed, I argue that contacts have a finite size and therefore inertia.

Depinning. Without inertia, such model predicts a depinning transition. The model corresponds to a d dimensional interface driven over a disordered pinning potential by a $d+1$ dimensional solid. Below a critical driving force, the interface is pinned by disorder. Above it, the interface moves at a constant velocity. At the critical force, the interface is marginally stable and avalanches appear whose size diverges as a powerlaw, successfully reproducing some features of earthquakes. Problematically, since elastic interactions between blocks are strictly positive (a failing block destabilises all other blocks) it has been shown theoretically that stick-slip is impossible: the system cannot build up "overstress".

Fracture. It is a known experimental fact that the system can build up an overstress before it fails catastrophically. At this point, slip starts by a fracture-like object that unzips the interface, whose front velocity and surrounding stress field are well described by fracture mechanics.

How is an overstress build up? I argue that these two facts are not contradictory. The effect of inertia, ignored in depinning, is consequential. Blocks that come close to failure at the very end of a slip event have a high probability to be failed by the mechanical noise. This results in an 'armoured' interface that can build up an overstress. With x the distance to yielding locally, this corresponds to $P(x) \sim x^\theta$ with $\theta > 0$, but whose value depends on the surface roughness in some way.

Rheology. The effect of inertia is consequential in two more ways. First, the failure of a block redistributes stress among neighbouring blocks by elastic waves. Blocks thus receive transient stress overshoots causing them to fail prematurely such that they too emit waves. This constitutes to a dynamic weakening such that the interface is *velocity weakening*, well described by rate-and-state friction laws (blue curve). Second, during the start of a slip event, the inertia of the surrounding elastic bulk provides a stabilising effect (quantified in the literature), such that the effective rheology is non-monotonic (red curve), with the minimum the "dynamic friction coefficient" denoted f_c.



When does slip start? Due to the disorder f_c varies in space. Consequently, a microscopic event nucleated at f_c can grow to a size ℓ with a finite probability, implying $P(\ell) \sim \ell^{-\tau}$ with $\tau > 0$. At a load $f > f_c$ disorder can only stop a propagating avalanche if $l < l_c \sim |f - f_c|^{-\nu}$ (with ν related to the fluctuations of stress after slip). However, due to the armouring, events are not numerous upon increasing the load ($\sim (f - f_c)^{\theta+1}$) such that practically one observes a diverging avalanche scale $l_{\max} \sim (f - f_c)^{(\theta+1)/(\tau-1)}$. Slip happens when $l_{\max} \sim l_c$, setting the "static friction coefficient".

Selection of publications

[1] T.W.J. de Geus and M. Wyart. Scaling theory for the statistics of slip at frictional interfaces. *Phys. Rev. E*, 106 (6):065001, 2022. doi: 10.1103/PhysRevE.106.065001. arXiv: 2204.02795.

[2] E. El Sergany, M. Wyart, and T.W.J. de Geus. Armouring of a frictional interface by mechanical noise. *arXiv preprint: 2301.13802*, 2023. doi: 10.48550/arXiv.2301.13802.

[3] T.W.J. de Geus, M. Popović, W. Ji, A. Rosso, and M. Wyart. How collective asperity detachments nucleate slip at frictional interfaces. *Proc. Natl. Acad. Sci.*, 116(48): 23977–23983, 2019. doi: 10.1073/pnas.1906551116. arXiv: 1904.07635.