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Failing softly:
on the mechanics of tearing and cutting soft materials

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In the common sense, soft is any material capable of deforming consistently without applying an excessive force, so that its deformation can be felt by hand or seen with the naked eye. However, this statement falls short of capturing the whole of soft matter features. In real life, soft materials are employed for their ability to accomodate large deformations with minimal damage. This explains why elastomers are attractive for joints, seals and adhesives, and for implants inside the human body. In nature, living organisms rely on the ability of soft tissues to provide protection to vital parts. Skin is our soft armour.

But how is this possible? We know by experience that stretching and tearing apart a rubber band is a hard work, whereas even a small flaw in a glass slab can lead to a sudden catastrophic failure. The glass elastic modulus is orders of magnitude larger than that of skin, so the response observed might appear surprising. Understanding the mechanics lying behind the behaviour of soft materials, including elastomers and biological tissues, is a keystone of the design of new materials and tools, with relevant applications in mechanical engineering, medicine and robotics.

This talk is centred on the mechanics of damage and fracture of soft materials, with a peculiar focus on biological tissues and artificial phantom materials employed by scientists for testing and modelling. At the same time, we investigate in detail the mechanics of cutting, showing common treats and differences with the plain process of tearing. Indeed, besides being a daily presence in our lives, cutting of soft matter plays a central role in the food processing industry and the medical sector.

We provide an exhaustive description of the fracture process in soft materials, starting from the effect of large strains on the crack-tip of hyperelastic materials with strain hardening, and highlighting the differences with the traditional linear elastic fracture mechanics. Rate-dependent effects, associated to various dissipative processes, are another relevant aspect to consider. We show the effect of the strain rate on the fracture energy of soft materials with a porous microstructure, through finite element simulations which adopt visco- and poro-hyperelastic material models.

In relation to cutting, we illustrate the concept of sharpness and see how it affects the mechanism of energy conversion leading to cut propagation. In particular, we identify a fundamental interaction occurring in soft materials, between crack blunting and a length scale of the cutting instrument. Finally, we describe the development of a robust computational algorithm to simulate cutting, and show its application to a complex problem of mixed-mode propagation occurring during the penetration of flexible needles with asymmetric tips.

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[1] This talk is derived from the author's PhD dissertation at University of Parma