rusty-tip
Automating STM/NC-AFM Tip Preparation
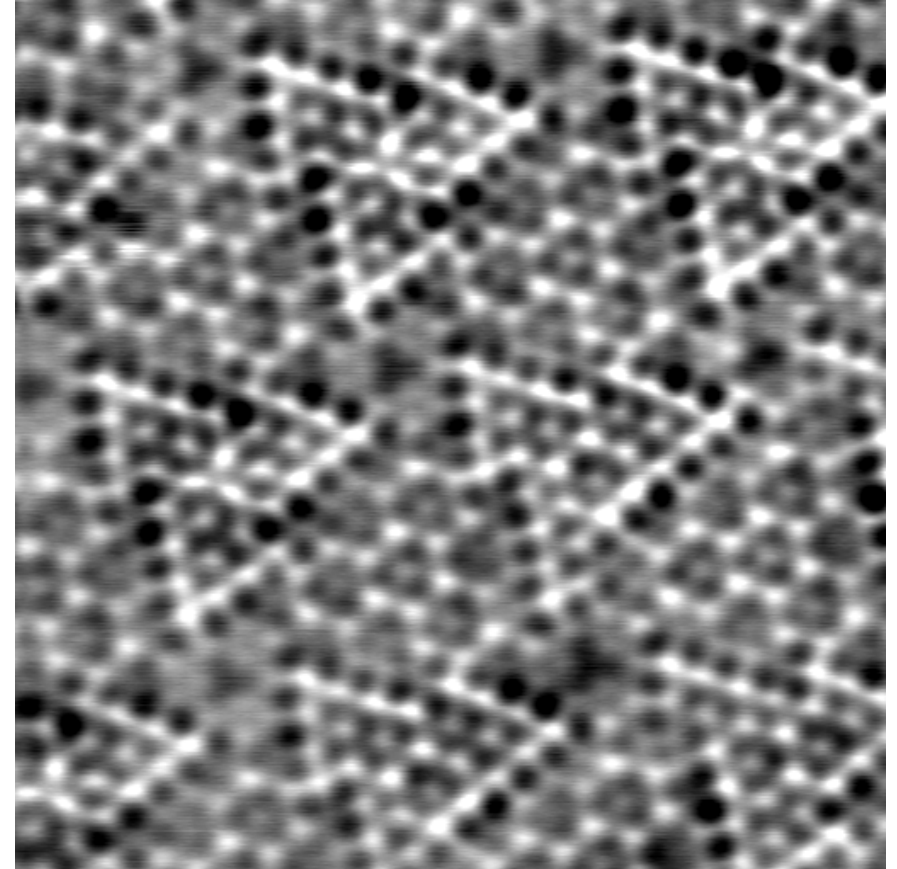
Martin Kronberger — github.com/kronberger-droid
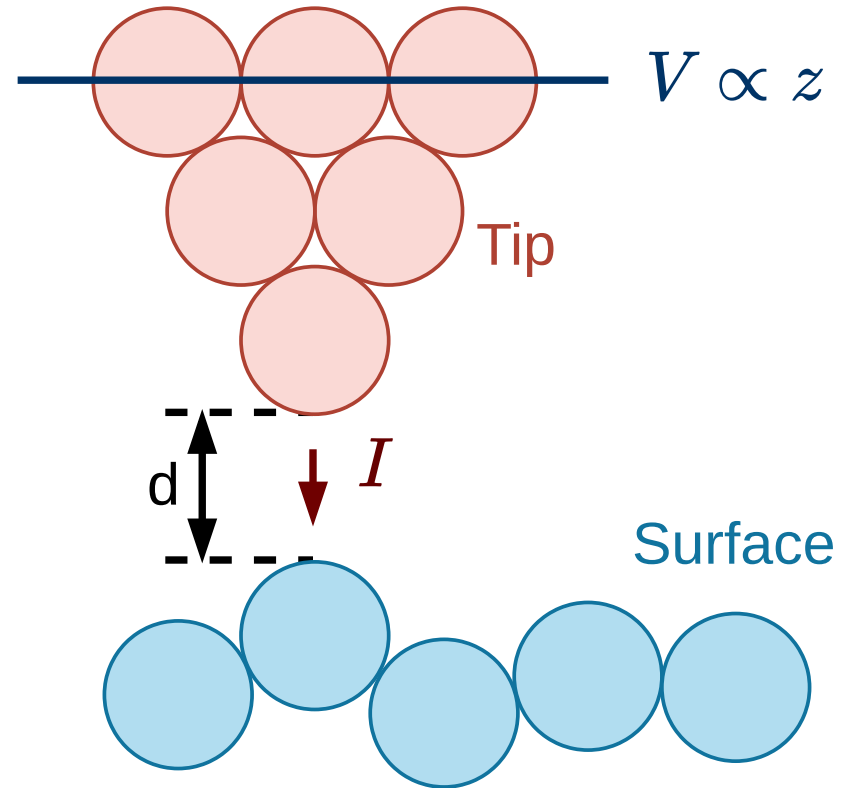
Institute for Applied Physics – Surface Physics Group
Technical University Vienna

Content

- SPM imaging quality depends critically on the **tip**

- Tip preparation is a manual, experience-driven process

- Goal: develop a software framework in Rust to **automate tip preparation** for STM/ncAFM

- Make the process more **reproducible** and less reliant on individual expertise
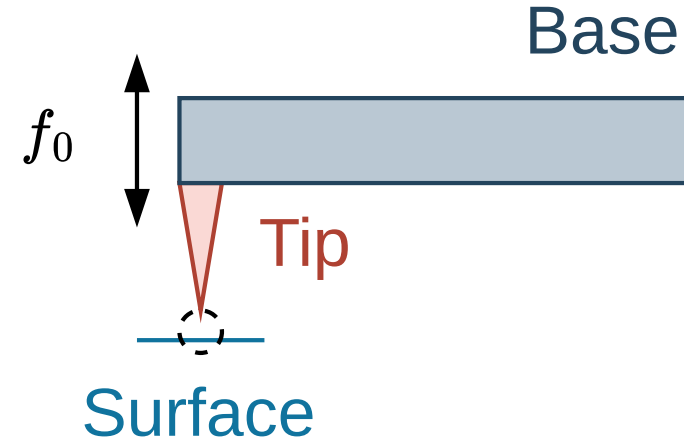

Hütner et al. (2024) [2]

Scanning Tunneling Microscope (STM)

- A bias voltage is applied between tip and sample

- Electrons tunnel across the vacuum gap

- The tunneling current I depends exponentially on the tip–sample distance

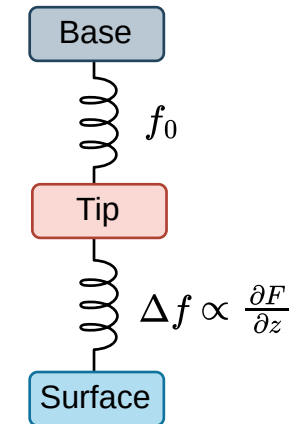- Feedback keeps I constant $\rightarrow$ tip traces the surface topography

$V \propto z$

Tip

d

I

Surface

Non-Contact AFM

- Cantilever vibrates at its resonance frequency

- Tip–surface interaction shifts the frequency by Δf

- Δf is proportional to the force gradient

- A low negative Δf at the surface often indicates a **sharp tip**
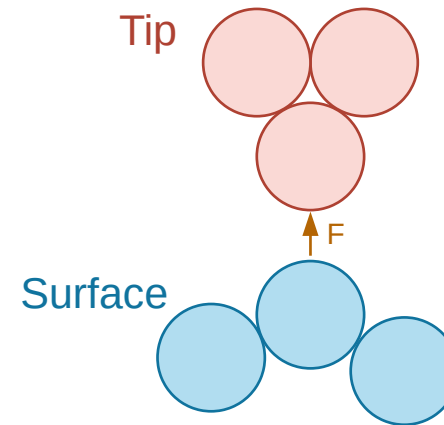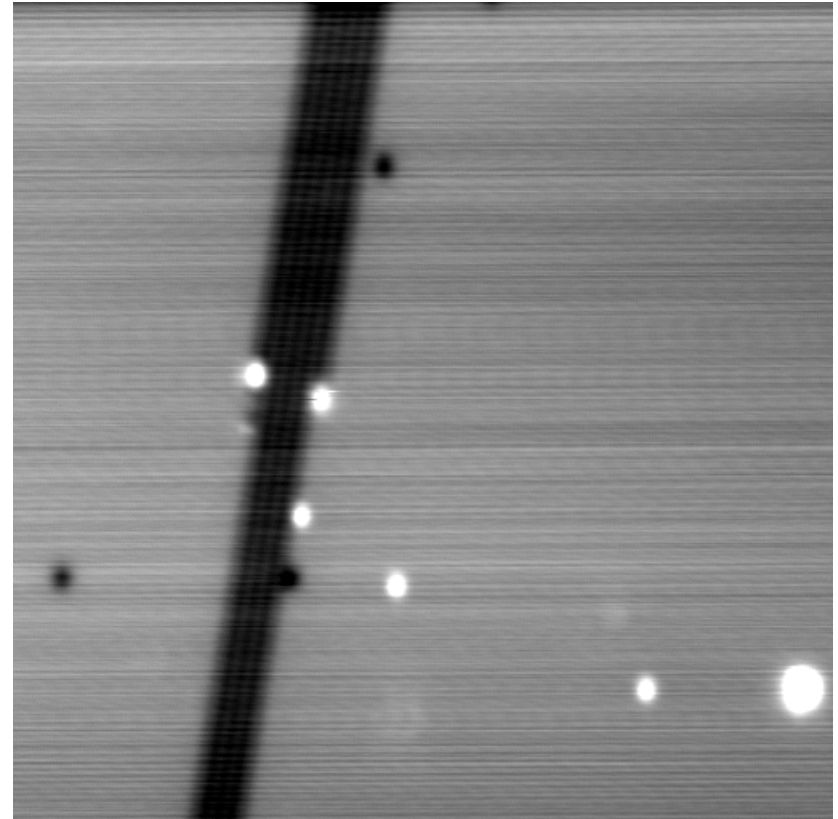
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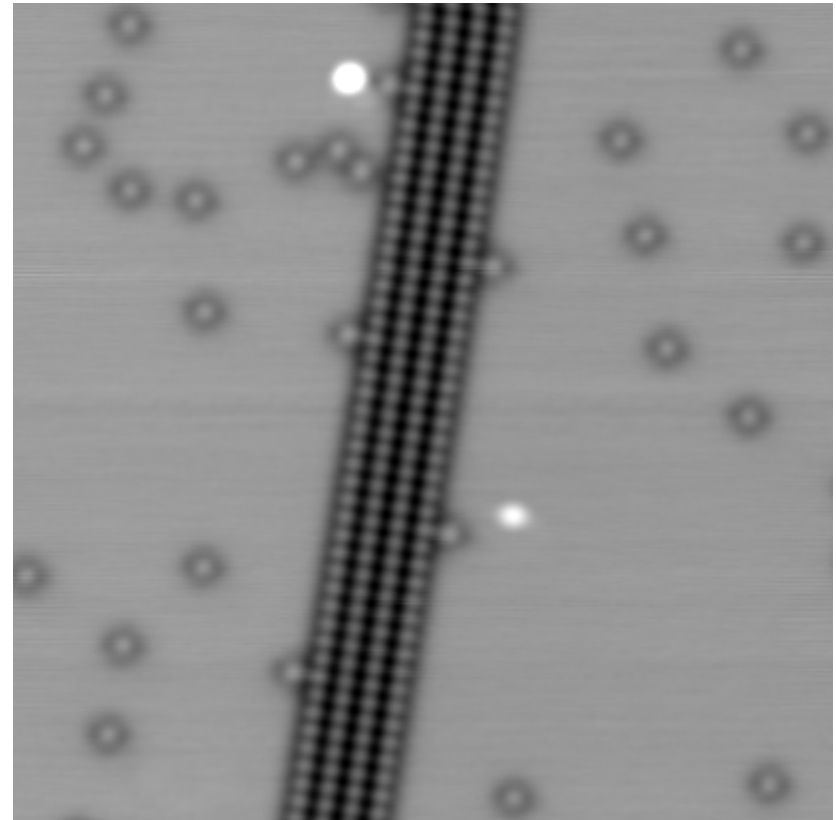
What We Can Automate Now

- **Shape** tip on Au(110), coat with Cu on Cu(110)

- Pulse and reposition until Δf is in the sharp range

- Verify tip stability via bias sweep

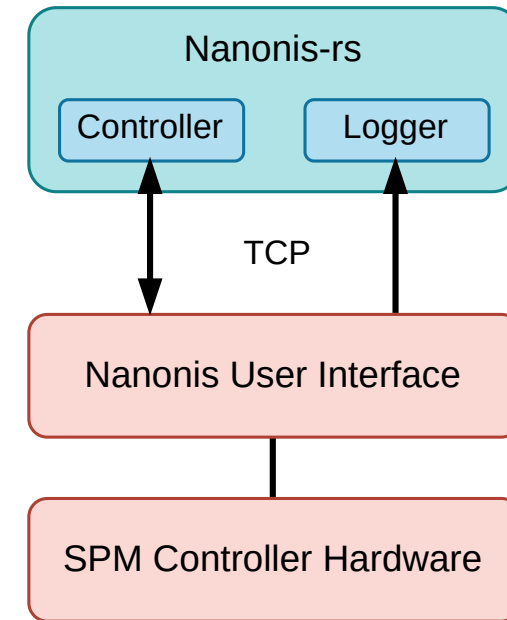Courtesy of D. Kugler

What Comes Next

- Dose O_2 on Cu(110) $\rightarrow$ CuOx rows

- Dip tip into CuOx rows to pick up a cluster

- Image a known surface to verify the tip produces the **expected atomic contrast** [1]

- Check tip symmetry by looking at surface impurities

Courtesy of D. Kugler

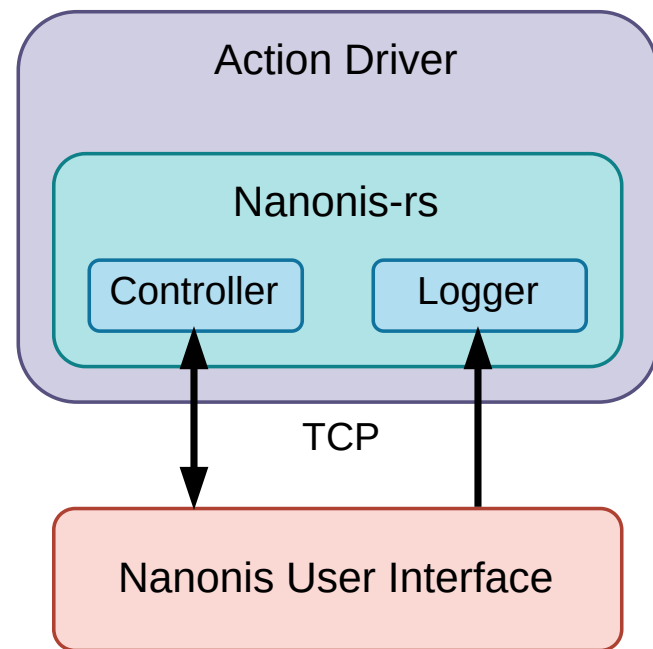**nanonis-rs** [3]

- Low-level TCP protocol and parser

- Covers **all** functions available on Nanonis-controlled machines
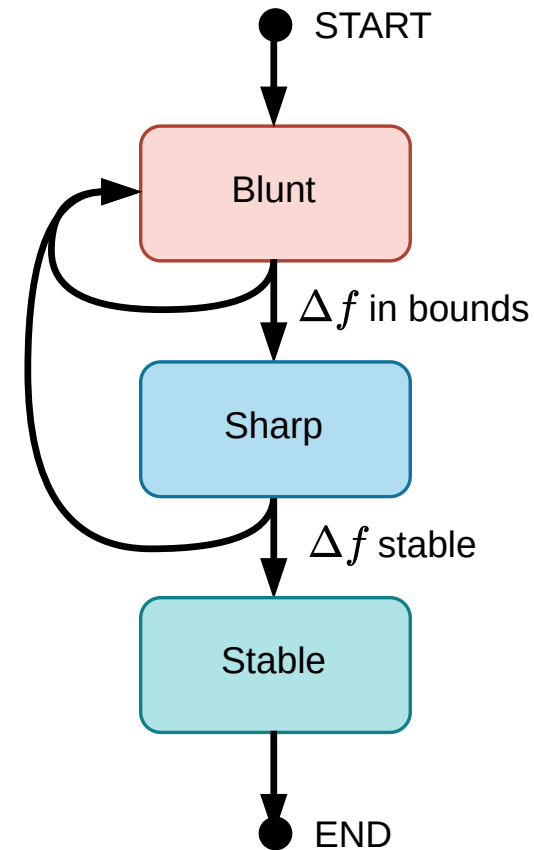
- High-throughput TCP logger

Action Driver

- Higher-level abstraction over nanonis-rs

- **Action-based system**: each action combines multiple low-level calls

- Makes it possible to log metric and metadata for actions

- Buffered TCP reader for data history analysis

rusty-tip [4]

- Uses the Action Driver under the hood

- **State machine** correlating machine states with action loops

- Three states: **Blunt** $\rightarrow$ **Sharp** $\rightarrow$ **Stable**

- Logs important metrics for actions

State machine diagram: START $\rightarrow$ Blunt; Blunt $\rightarrow$ Sharp (Δf in bounds); Sharp $\rightarrow$ Stable (Δf stable); Stable $\rightarrow$ END. Loop back from Sharp to Blunt.

Outlook

- Automate **tip conditioning** and verification

- Use **image recognition** to evaluate tip quality from images

- Optimize action parameters like pulse voltage via Bayesian optimization

- Extend nanonis-rs to support other SPM workflows beyond tip preparation

- Long-term: fully autonomous experiment — from tip prep to data acquisition

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References

1. Mönig et al., "Submolecular imaging by noncontact atomic force microscopy with an oxygen-terminated copper tip," *Nanoscale* **13**, 18624 (2021).
   https://doi.org/10.1039/d1nr04080d

2. Hütner et al., "Stoichiometric reconstruction of the Al_2O_3(0001) surface," *Science* **385**, 1241–1244 (2024).
   https://doi.org/10.1126/science.adq4744

3. nanonis-rs — https://github.com/kronberger-droid/nanonis-rs

4. rusty-tip — https://github.com/kronberger-droid/rusty-tip