Lecture: P1_Wk3_L5

Contact Mode Scans

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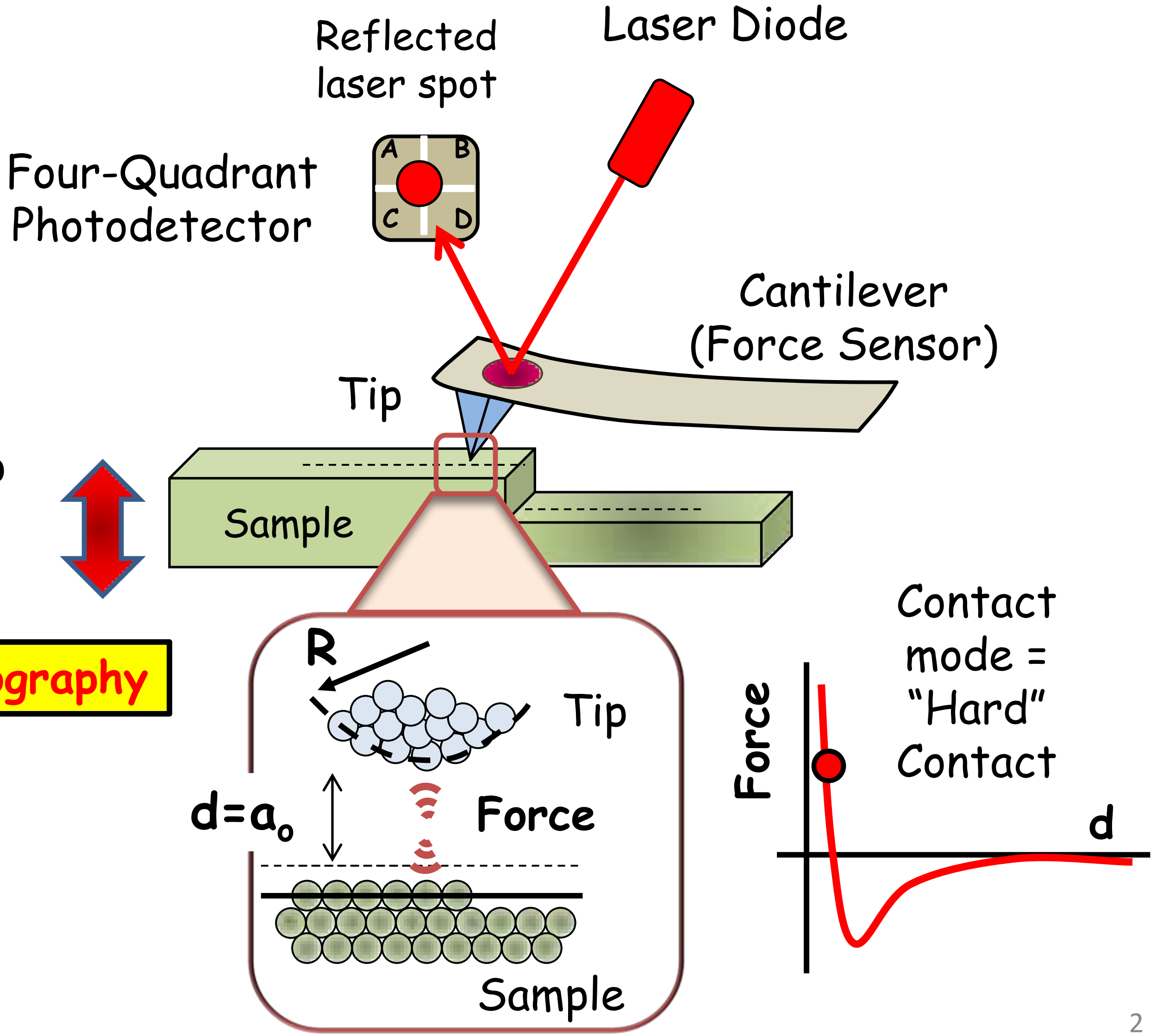
The Purpose of a Microscope is to Obtain an Image



Move sample to keep deflection of cantilever constant

Sample Motion = Topography

Contact Mode AFM

Advantages:

- Easier than dynamic AFM
- Somewhat higher scan speeds
- "Atomic resolution" is possible on flat samples
- Possible to scan rough samples with large changes in vertical topography

Disadvantages:

- Lateral forces can displace loosely bound particulates and destroy the sample and/or tip
- Capillary forces from adsorbed liquid layer can cause high adhesion in addition to tip-sample interaction
- Reduced spatial resolution, with damage to softer samples

Overcoming Inherent Barriers

- AFM experiments are not easy – they often require an expert operator
- Each sample and each cantilever seems to require realignment and readjustment
- AFM experiments just take time . . . .
- The results of an AFM experiment are difficult to interpret

While all true, any effort is worthwhile simply because the information cannot be obtained in other ways.

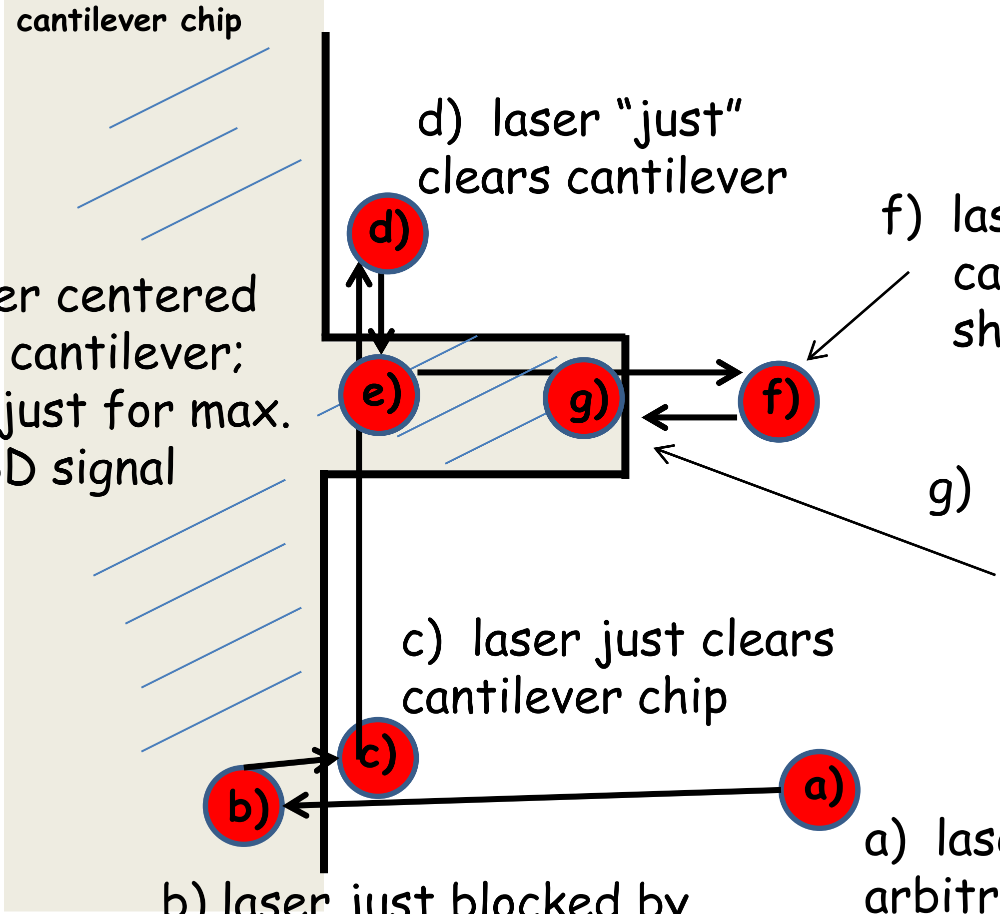
The key point is to match effort with understanding. Try to replace prescription processes with knowledge.

Steps for Contact Mode Scanning - Overview

1. Prepare and mount sample
2. Select and mount cantilever; is k of cantilever known?
3. Align laser onto cantilever
4. Purge system with dry nitrogen
5. Wait for system to stabilize
6. Realign laser
7. Select X scan range and scan lines/s (tip speed). Check to make sure the **tip speed** does not exceed ~50 μm/s.
8. Select Y scan range - usually equals the X scan range
9. Select Z gain of system to match height variations on sample
10. Select force setpoint
11. Coarse Approach - efficiently move tip to sample until setpoint is achieved
12. Scan to optimize feedback.
13. Increase tip speed if required. Repeat step 12.
14. Zoom into interesting features as required, reducing tip speed as necessary.
15. If everything is working well, scan as long as you can!
16. Disengage tip from sample

Experience has proved time and again that good sample preparation is crucial

Positioning the Laser



a) laser is at some arbitrary point

b) laser just blocked by cantilever chip

c) laser just clears cantilever chip

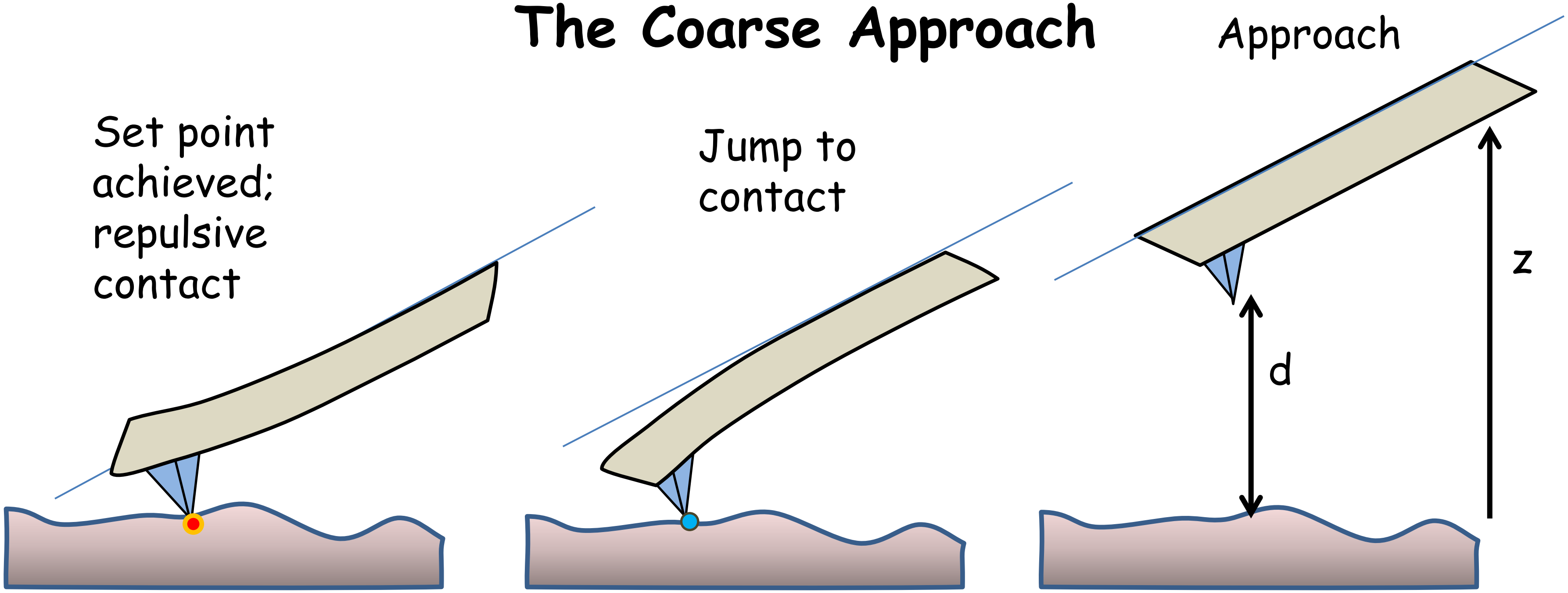
d) laser "just" clears cantilever

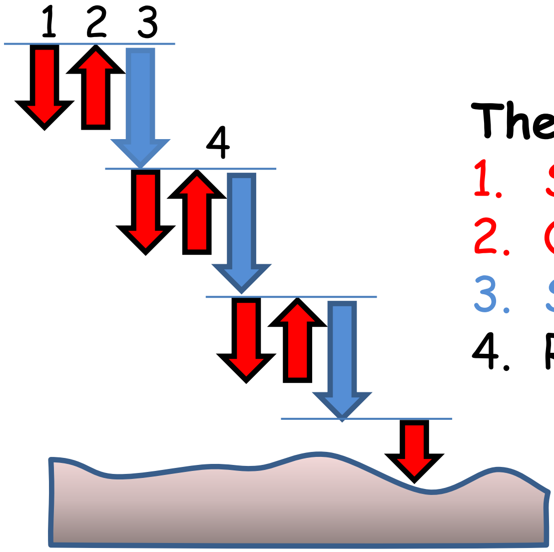
e) laser centered on cantilever; adjust for max. PSD signal

f) laser "just" falls off cantilever; PSD signal should disappear

g) Move laser back onto cantilever; PSD signal should reappear; optimize

The Coarse Approach





The coarse approach sequence:

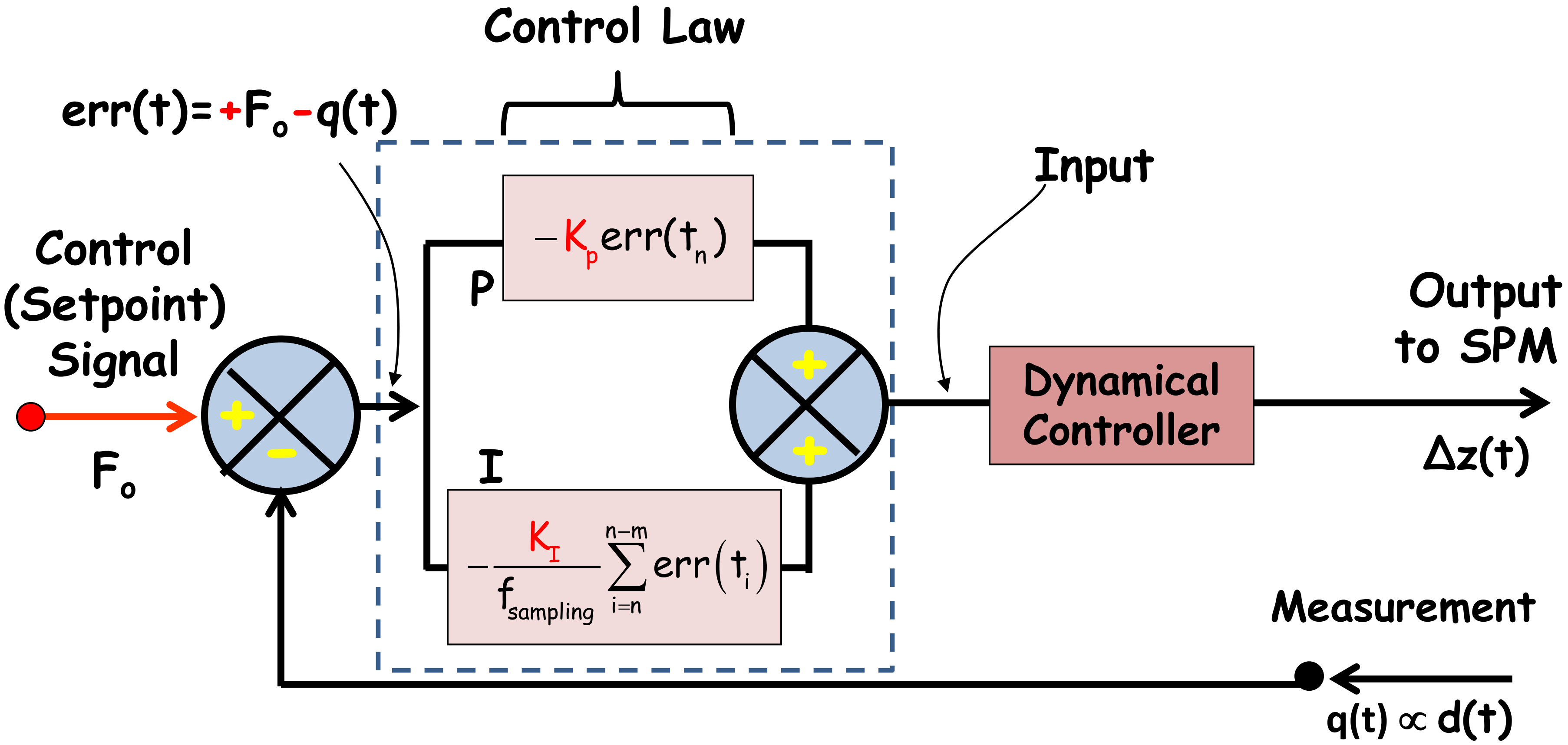
1. Slowly expand z-piezo
2. Quickly retract z-piezo
3. Stepper motor advance
4. Repeat until force setpoint is reached

Optimizing the Feedback Loop

Experience has proved that setting feedback parameters is a method of successive approximations.

Real-time tuning of AFM feedback loops is required because….

The AFM Feedback Loop



Control Law

$err(t) = +F_o - q(t)$

Input

Control (Setpoint) Signal

F_o

P

$-K_p err(t_n)$

I

$$-\frac{K_I}{f_{sampling}} \sum_{i=n}^{n-m} err\left(t_i\right)$$

Dynamical Controller

Output to SPM

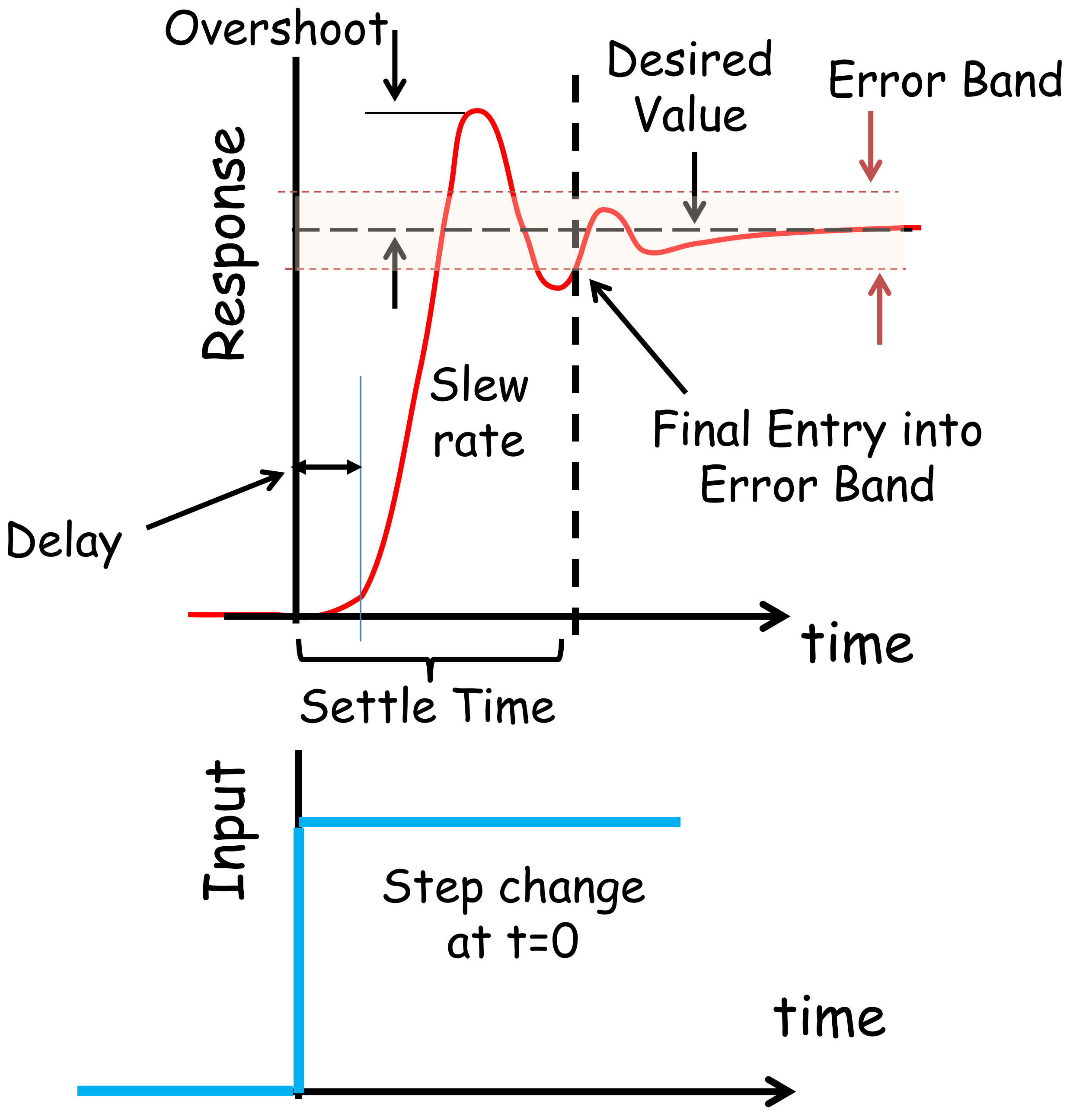
$\Delta z(t)$

Measurement

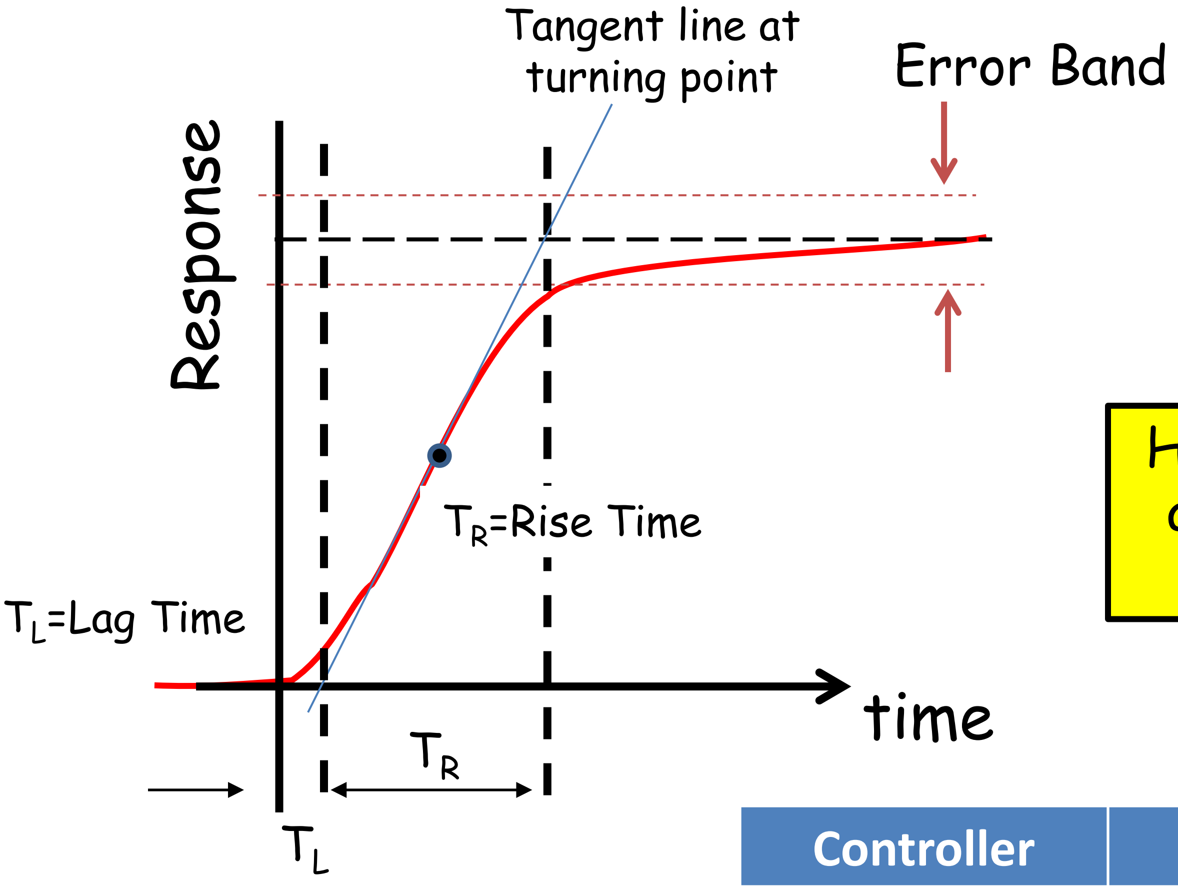
$q(t) \propto d(t)$

- The proportional (P) controller allows the probe to follow smaller, high frequency features by adjusting K_p
- The backward integrator (I) controller allows the probe to follow larger, low frequency features by adjusting K_I
- $f_{sampling}$ should be ~10x the frequency of the most relevant feature that is being measured

Typical Feedback Loop Response to a Step Change



The classic Ziegler-Nichols Tuning Rule – one example



How to measure T_L and T_R in an AFM experiment??

"Typically" gives an overshoot of ~25% and good settling time.

Controller	K_P	K_I
P only	T_R/T_L	0
PI	$0.9\,T_R/T_L$	$0.27\,T_R/T_L^2$

Trends

Increasing K_P tends to decrease the rise time, increase the overshoot, has little effect on the settling time, and decrease the steady state error

Increasing K_I tends to decrease the rise time, increase the overshoot, increase the settling time, and eliminate the steady state error

One strategy:
Use K_P to optimize the rise time.
Use K_I to better track large features.

Why a tuning rule may not work

You assume that some tuning procedure is valid, but for some reason, it is not. Confusion results.

For example:

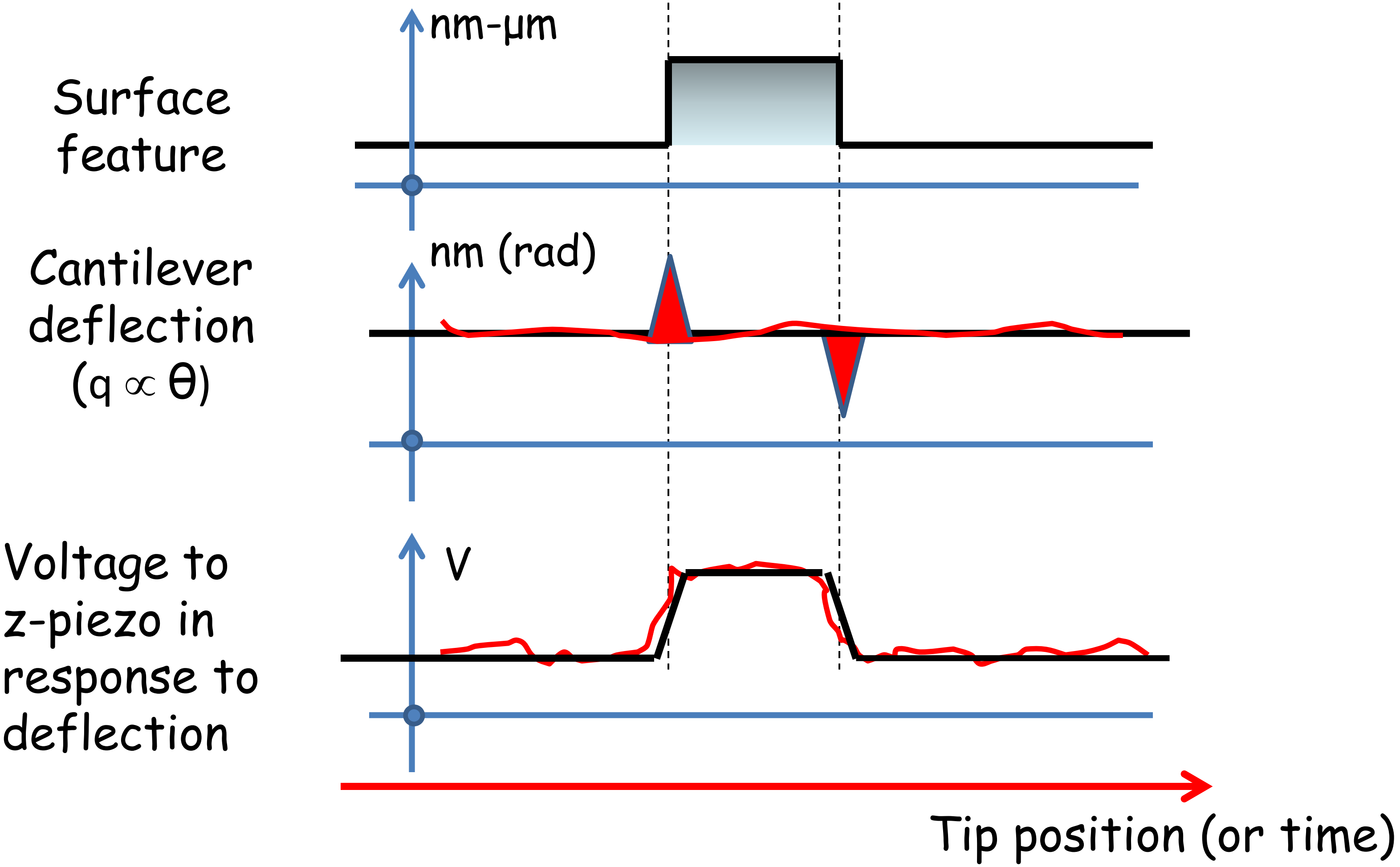
- The dilemma of mutually exclusive desires: The Ziegler-Nichols tuning rule is meant to give your PI loop an acceptable disturbance rejection performance. This operation may not be consistent with good dynamic tracking.

- Overly aggressive gains might make the system respond too quickly, producing erratic behavior.

- A pure time delay assumption may not match reality.

Moral: it is easy to have in mind a tuning rule that simply does not work for a particular application, and you might not even realize it.

What actually occurs



Surface feature

Cantilever deflection (q ∝ θ)

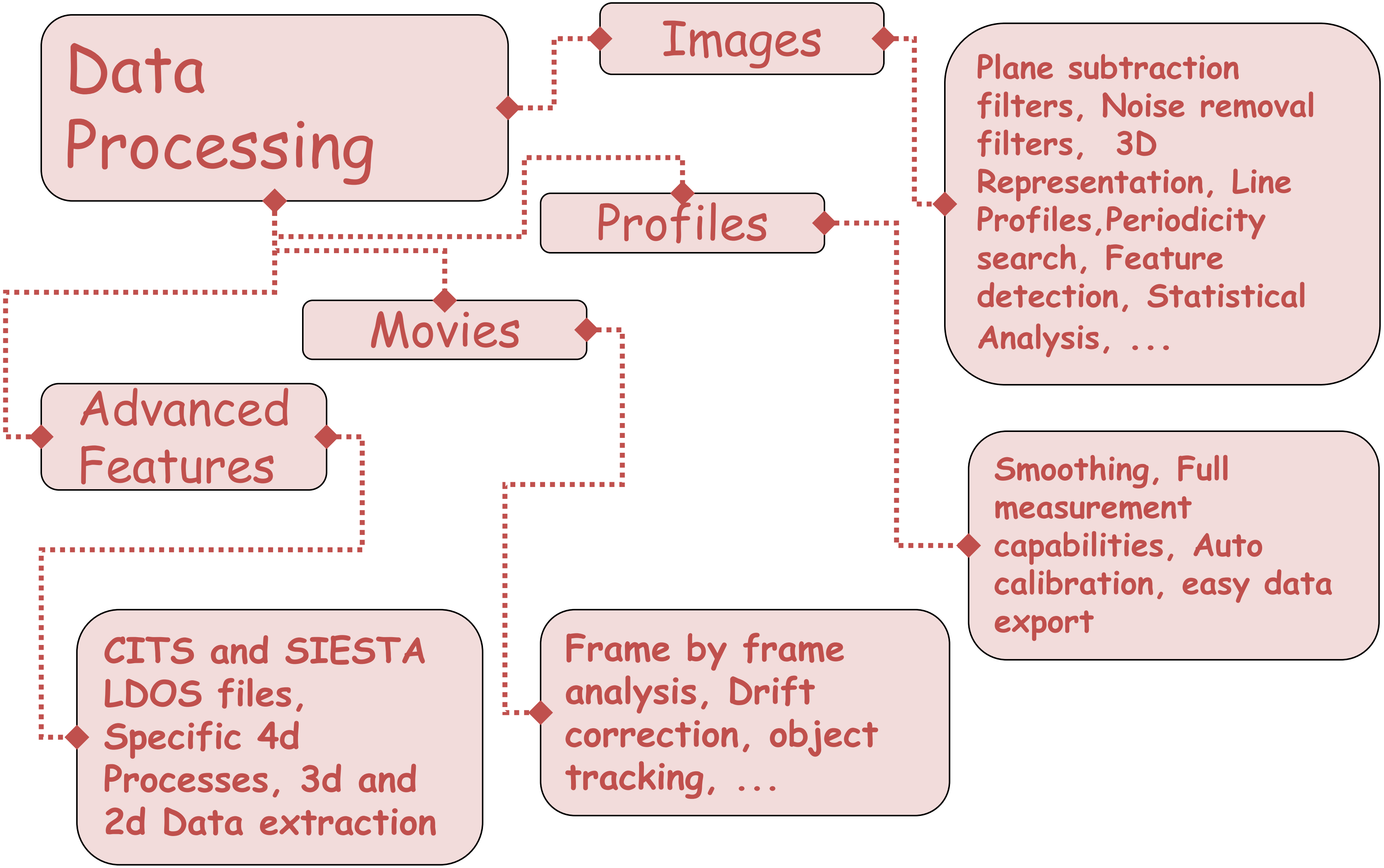
Voltage to z-piezo in response to deflection

Tip position (or time)

An Empirical Procedure for Setting K_P and K_I

- Select a scan speed and begin to acquire an image
- Systematically increase K_P and K_I in steps until "grainy" noise appears across the image
- Systematically decrease K_P and K_I until the "grainy" noise disappears
- Readjust the set point. Lower loading forces will minimize probe tip damage!
- The feedback gains may need readjustment, since **set point, scan speed and feedback gain are interrelated**
- If scanning is too slow, increase scan speed and repeat procedure
- Finally, analyze the error map image. When the error map is minimal, then the feedback controls are optimized

Once you have the image – need versatile data processing software



Data Processing

Images

Plane subtraction filters, Noise removal filters, 3D Representation, Line Profiles,Periodicity search, Feature detection, Statistical Analysis, ...

Profiles

Smoothing, Full measurement capabilities, Auto calibration, easy data export

Movies

Frame by frame analysis, Drift correction, object tracking, ...

Advanced Features

CITS and SIESTA LDOS files, Specific 4d Processes, 3d and 2d Data extraction

WSxM: I. Horcas et al., Rev. Sci. Instrum. **78**, 013705 (2007).

Many Applications

Provides nanometer scale images of insulating surfaces with little or no sample preparation. Images reveal the three dimensional topography of surfaces.

- Quantify dimensions of features produced by optical and/or e-beam lithography
- Sample roughness analysis vs. processing conditions
- Step formation in thin-film epitaxial deposition
- Defects (e.g. pin holes) in oxides growth
- Grain size analysis of deposited metals
- Variations in material properties, including elasticity and adhesion
- Polymer composites
- Information about indentation at very small loads
- *In situ* analysis of changes in morphology with temperature
- many, many others….

Up Next: The AFM as a System