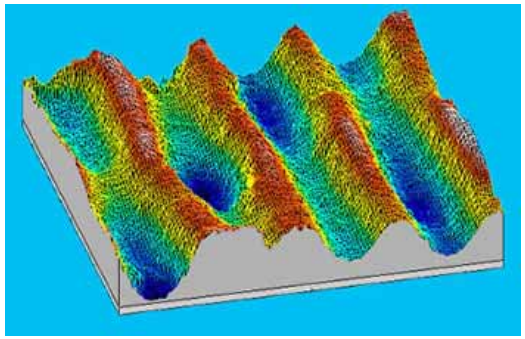
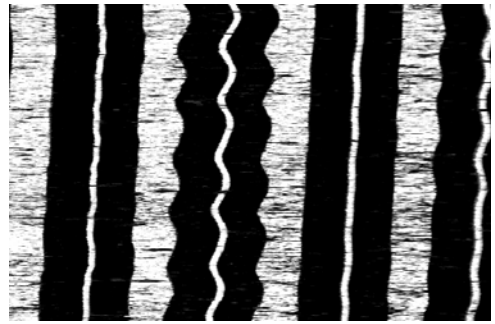




Imaging of Laterally and Vertically Grooved Analog Audio Recordings

Carl Haber

Lawrence Berkeley National Lab

Lawrence Berkeley National Lab

www.lbl.gov

- Founded in 1931 by E.O.Lawrence
- Oldest of US National Labs
- Operated by the University of California for the US Dept. of Energy
- 4000 Staff, 800 Students, 2000 Guests
- 14 Research Divisions including
  - Physics, Nuclear Science
  - Materials, Chemical Science
  - Life Sciences, Physical Bioscience
  - Energy and Environment, Earth
  - Computing
- Major facilities-
  - Advanced Light Source
  - Nat. Center for Electron Microscopy
  - Nat. Energy Research Super Computer Center
  - Joint Genome Institute

Collaboration and Support

Lawrence Berkeley National Lab: Earl Cornell, CH, Vitaliy Fadeyev, Robert Nordmeyer, Jian Jin, Mitch Golden

Library of Congress: Peter Alyea, Larry Appelbaum, Dianne van der Reyden, Elmer Eusman, Eric Hansen

UC Berkeley: Andrew Garrett (Linguistics), Victoria Bradshaw (Phoebe Hearst Museum of Anthropology)

Fantasy Studios: George Horn

EIF Fribourg - Switzerland

University of Southampton – UK

First Sounds

The LIBRARY of CONGRESS

NATIONAL ARCHIVES AND RECORDS ADMINISTRATION 1985

INSTITUTE of Museum and Library SERVICES

NATIONAL ENDOWMENT FOR THE HUMANITIES

THE ANDREW W. MELLON FOUNDATION

John Simon Guggenheim Memorial Foundation
Fellowships to Assist Research and Artistic Creation

America's Collections

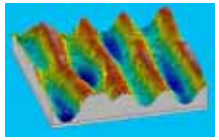
Fig. 4.1 U.S. Institutions Have Taken Responsibility to Preserve 4.8 Billion Collections Items	
Books/Bound Volumes	1.7 billion
Microfilm/Microfiche	1 billion
Natural Science Specimens	820.2 million
Photographic Collections	727.4 million
Archaeological Collections, individually cataloged	197.8 million
Unbound Sheets, cataloged in items	95.8 million
Online Files	54.6 million
Historic Objects	48.3 million
Recorded Sound	46.4 million
Unbound Sheets, cataloged in linear feet	43.6 million
Moving Images	40.2 million
Art Objects	21.2 million
Digital Materials	9 million
Archaeological Collections, cataloged in cubic feet	2.6 million

Heritage Health Index 2005

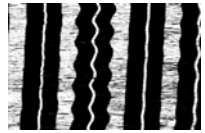
- US museums, libraries, and institutions collectively hold 4.8 Billion items
- 46.4 million sound recordings
  - 9.6 million are in grooved formats
  - 59% of these are in unknown condition
  - And there is the rest of the world
- Archivists want to reformat all pre-digital media since playback systems are not maintained
- **National Recording Preservation Act of 2000** "A bill to…maintain and preserve sound recordings and collections of sound recordings that are culturally, historically, or aesthetically significant…, " (Public Law 106-474; H.R.4846).

The Berkeley Optical Sound Restoration Project

- We are developing methods of optically restoring mechanical sound recordings **without contact** to the medium – like text scanning
- Address concerns of the preservation, archival, and research communities:
  - Preservation: Restore or stabilize delicate or damaged media
  - Access: Mass digitization of diverse media, automation
  - Assessment
  - Obsolete formats and legacy playback systems
- The approach evolved naturally out of methods of optical metrology, pattern recognition, image processing, and data analysis we use for physics research.



Non-Contact Digital Imaging

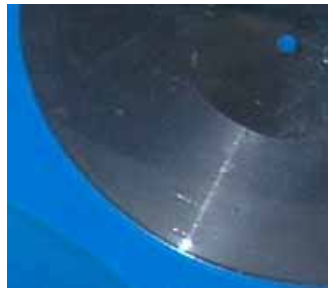


- Create a high resolution digital map of entire surface
- Computer plays record (image) with a virtual stylus
- Product
  - Standard digital sound files (ie .wav)
  - High resolution digital images which may be reanalyzed later as well
- Protects samples from further damage
- Repair existing damage through “touch-up”
- Reconstruct broken records
- Offload aspects of restoration to automated software

A “smart” copying machine for records

Sound Carrier Diversity and Condition

Wax cylinders
Fungus
Wax bloom



Al disc: oxidation

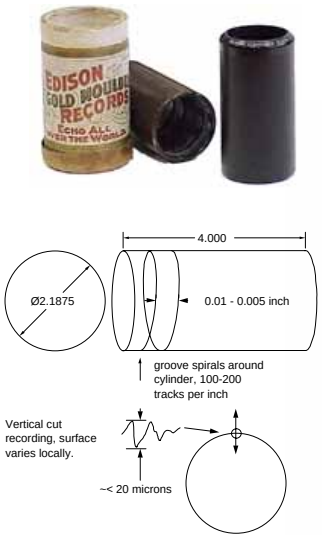
Acetate: flaking

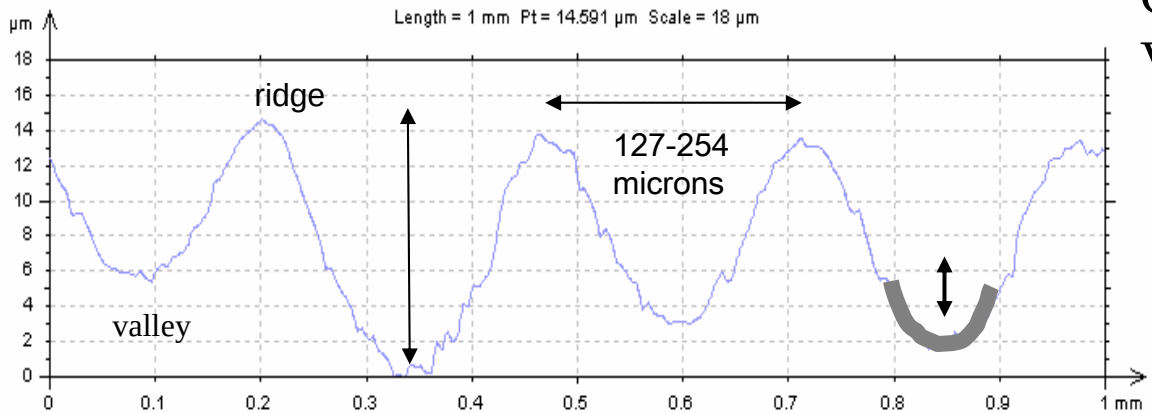
exudation

Plastic belts
breakage

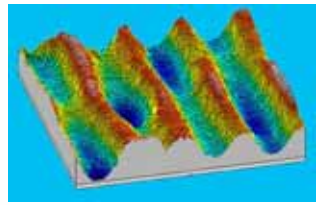
dirt

warpage



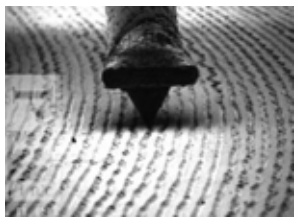


Cylinder surface
Vertical cut

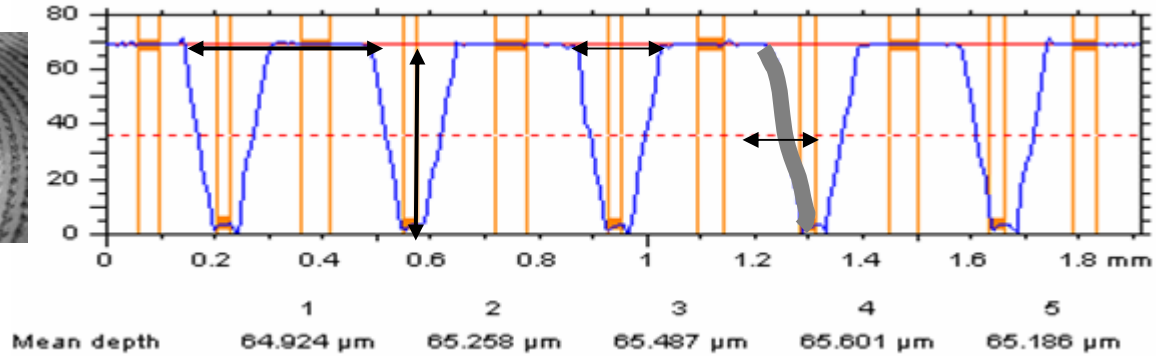


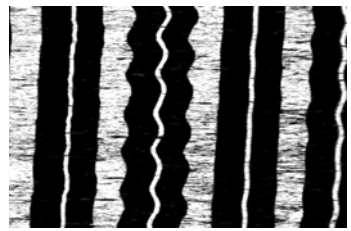
3D image

Disc surface
Lateral cut



400 µm 150 µm

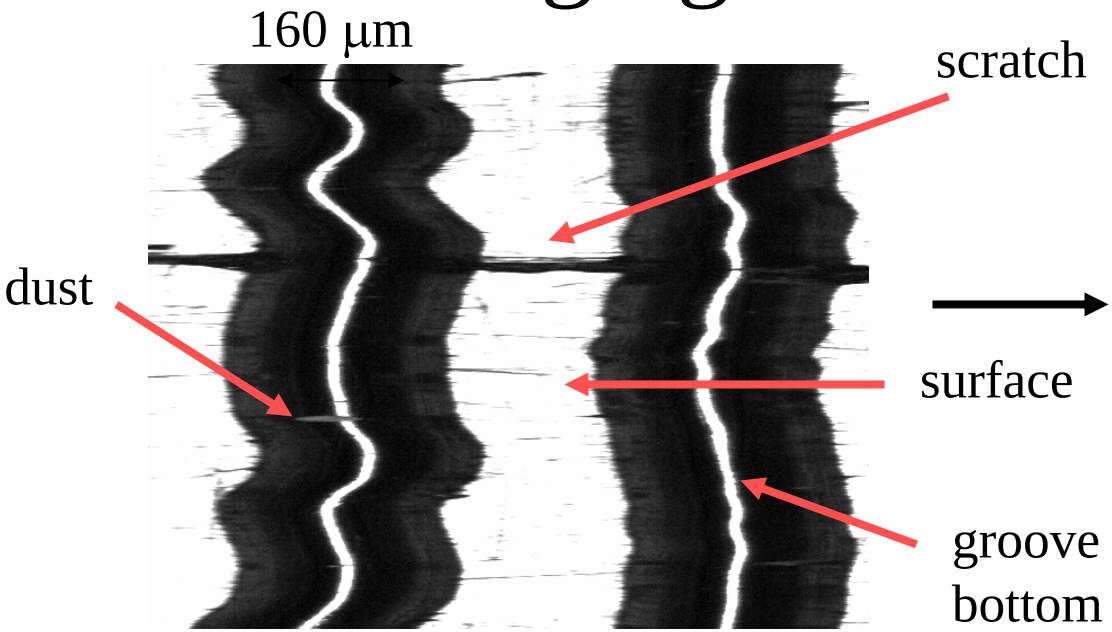


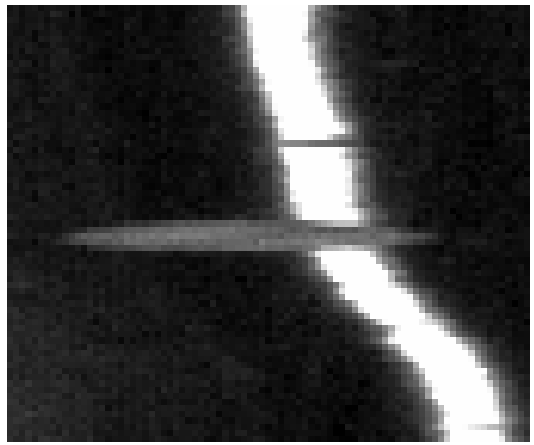


2D image

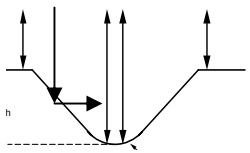
Audio is encoded in micron scale features which are >100 meters long.

2D Imaging: Electronic Camera

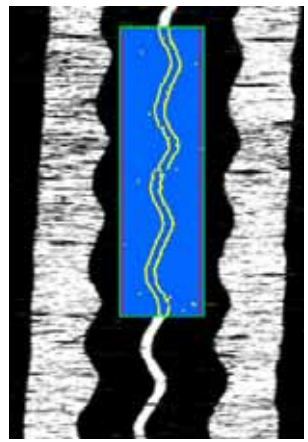




Coaxial illumination

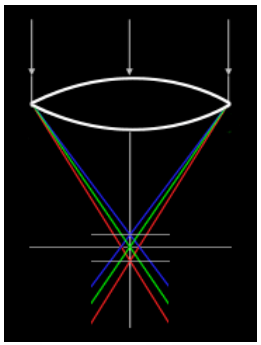


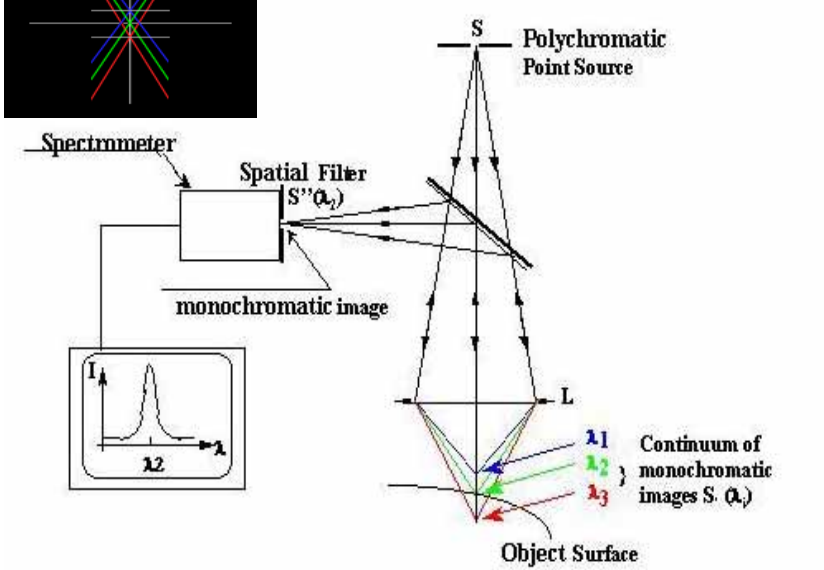
- Suitable for disc with lateral groove
- Require 1 pixel = ~ 1 micron on the disc surface
- High resolution yeilds narrow depth of field, 10 – 20 microns
- High speed cameras allow near “real-time” imaging
- Extract groove information from high contrast edge transitions

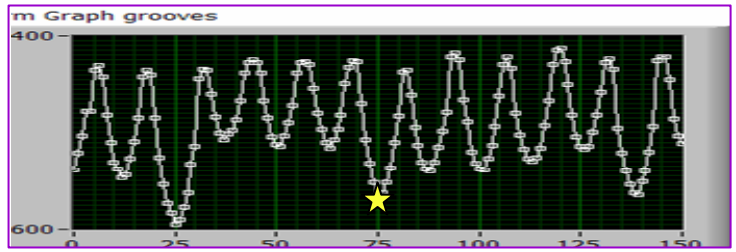


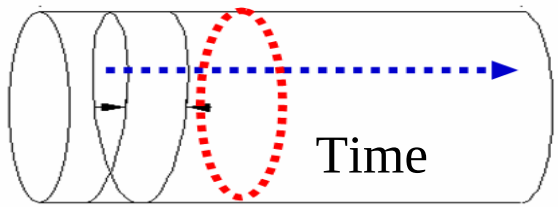
3D Imaging: Confocal Scanning Probe

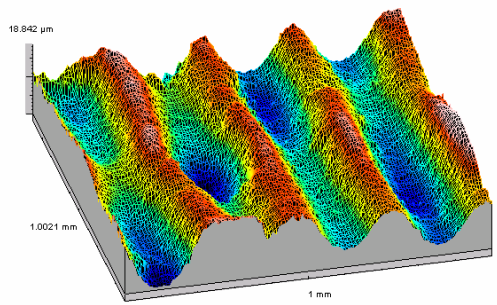
Required for cylinder with vertical groove modulation.







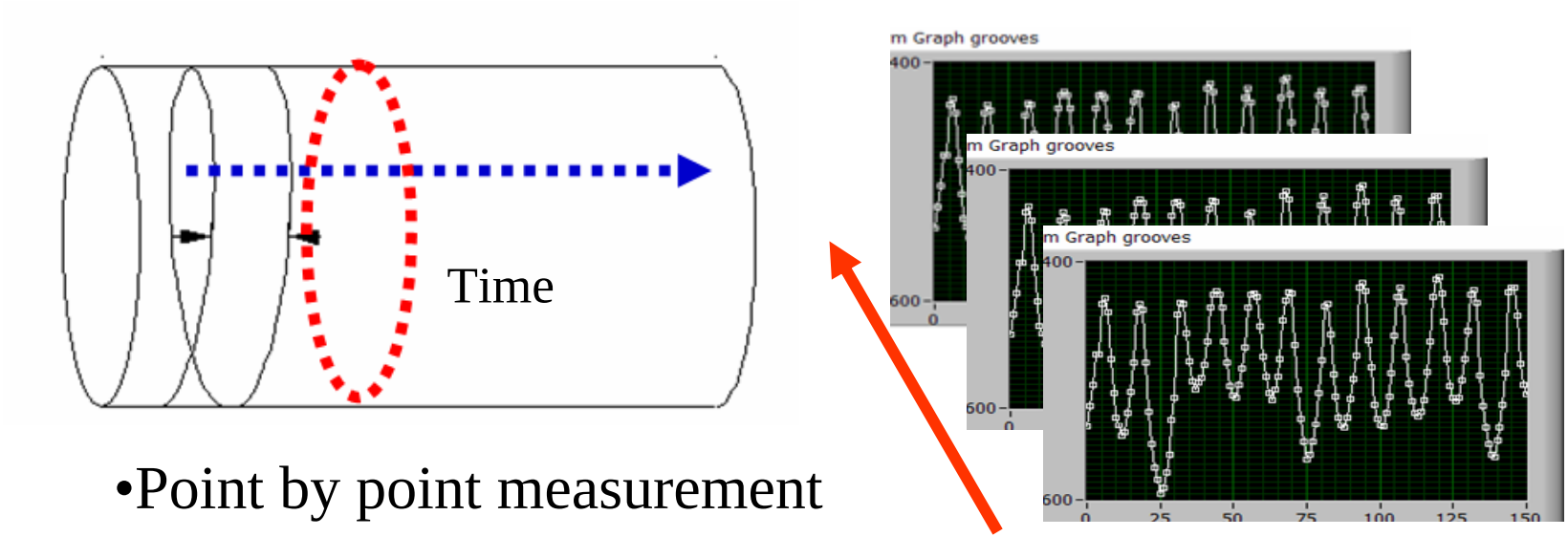




1 point at 2 KHz vs. 180 points at 1.8 KHz

3 days 30 minutes

Speed and Data

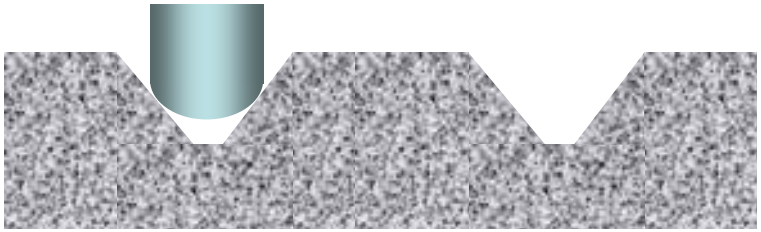


- Point by point measurement
- Exposure time per point
- Grid along time direction (red) = digital sampling
  - 0.02 degree = 18,000 samples = 48 KHz
- Grid along axis direction (blue) = points per profile
  - Typically 5 – 10 microns
- 1 probe: ~ 80 hours for 2-4 minutes of audio
- 180 probes: ~ 20 minutes (new multi-fiber probes)

Redundancy

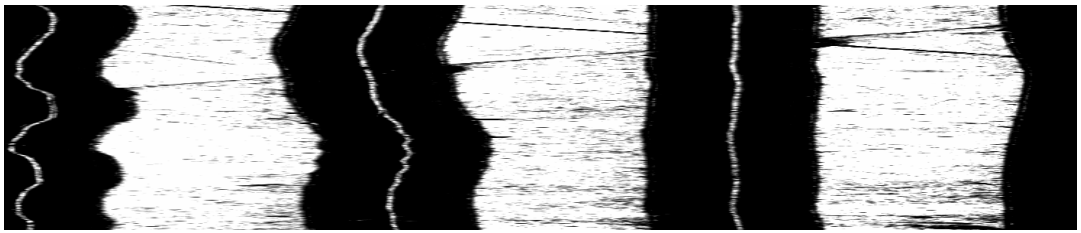
Audio stored in entire profile, signal averaging

Stylus



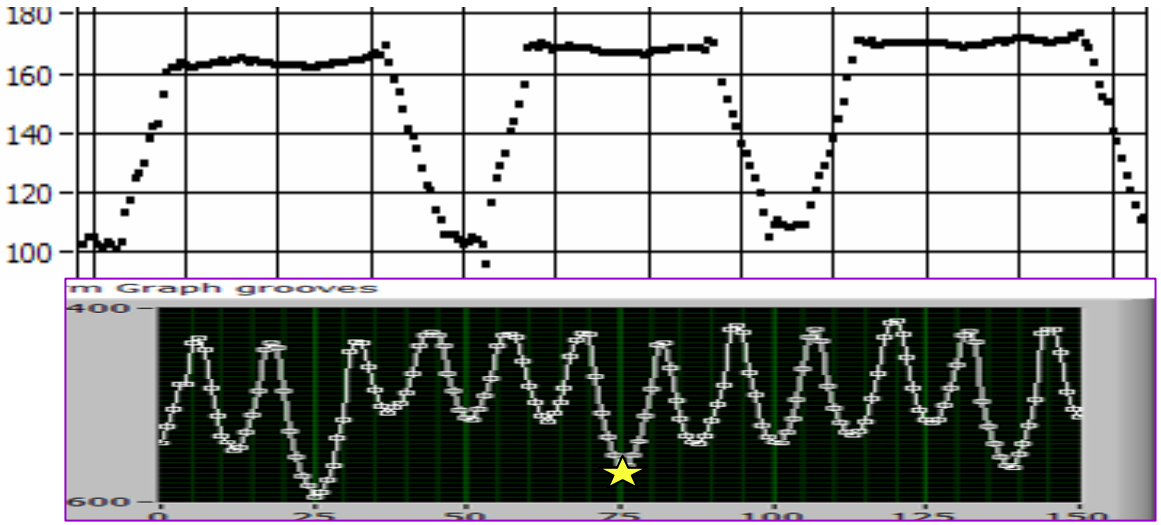
Stylus comes into contact at 2 points

2D



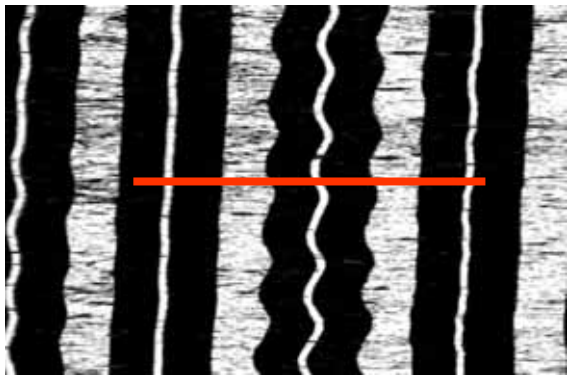
Measure the groove bottom with 2 points/slice

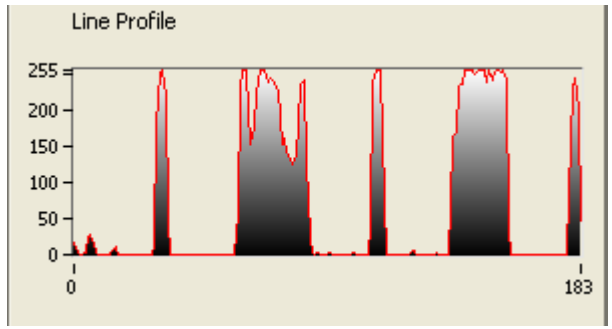
3D

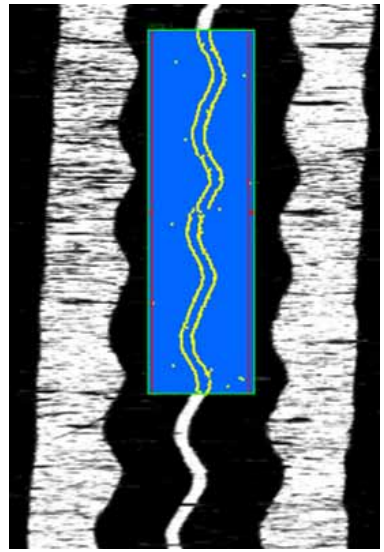


Measure the entire groove with ~30 points/slice

Image Analysis



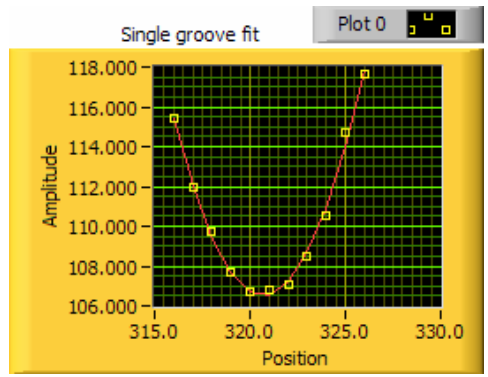




Feature extraction and measurement

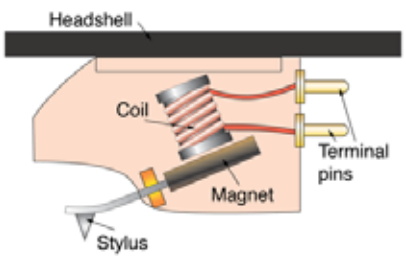
Measured width of features provide a natural noise detection and removal tool.

3D images are analyzed in an analogous fashion



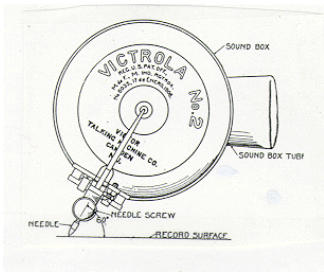
What is the relationship between "groove" and sound?

Electro-magnetic case

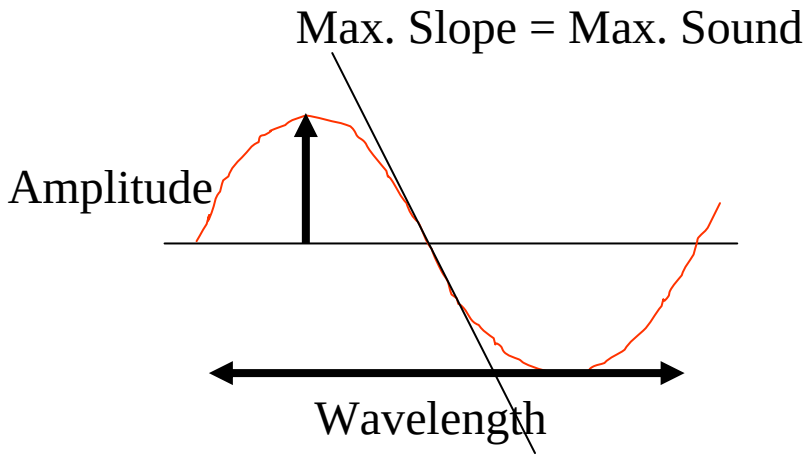


induction

Acoustic case



Diaphragm is over-damped to provide flat response



Sound = Stylus Velocity

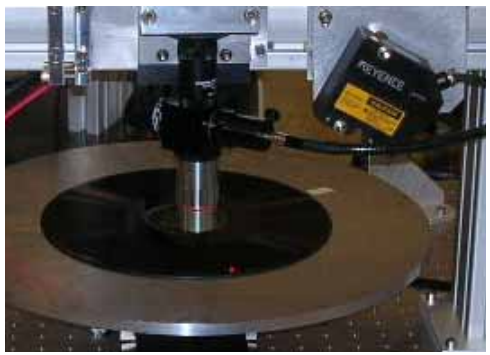
$$A_p = \frac{v_p}{2\pi f}$$

("constant velocity condition")

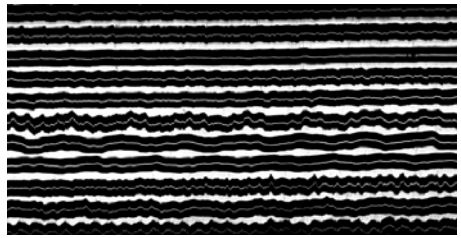
Projects Underway

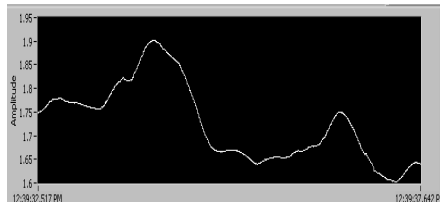
- Early tests led to support from the Library of Congress and others.
- IRENE: a fast 2D optical scanner for disc records (NEH 2005)
  - Digital access to the most common media + special formats
  - Installed 2006 at Library of Congress, evaluation, upgrade
- 3D: develop a fast scanner for cylinders and discs (IMLS 2007)
  - Preservation and restoration of early and damaged recordings
  - Attempt to reach ultimate measurement detail and audio quality
- Special Studies: damaged, broken, unplayable, and rare media
  - Wax field recorded and dictation cylinders
    - UC Berkeley Hearst Museum Native American recordings
    - Ca State Parks: Jack London dictations
  - Lacquer discs: personal correspondence, studio out-takes, radio shows
  - Dictation belts (NARA) Presidential history
  - Phonautograms: earliest sound recordings

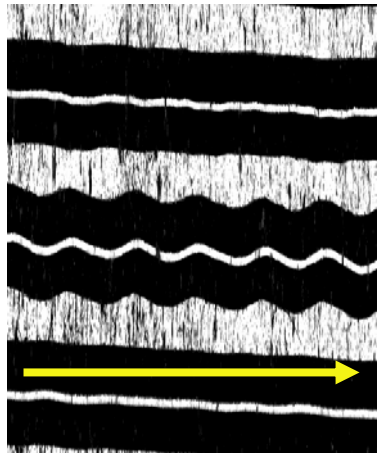
I.R.E.N.E



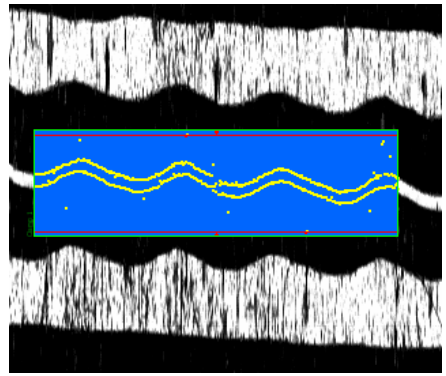
Line scan



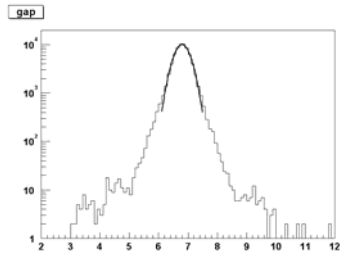




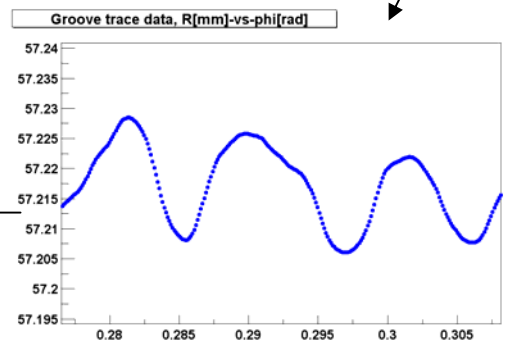
Time
Pixels = 104 KHz

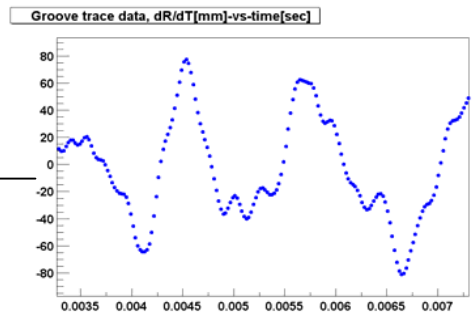


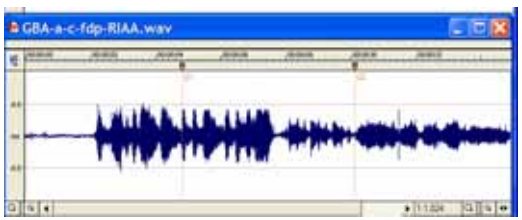
Width across
groove bottom



Measure slope
at each point
(stylus velocity)



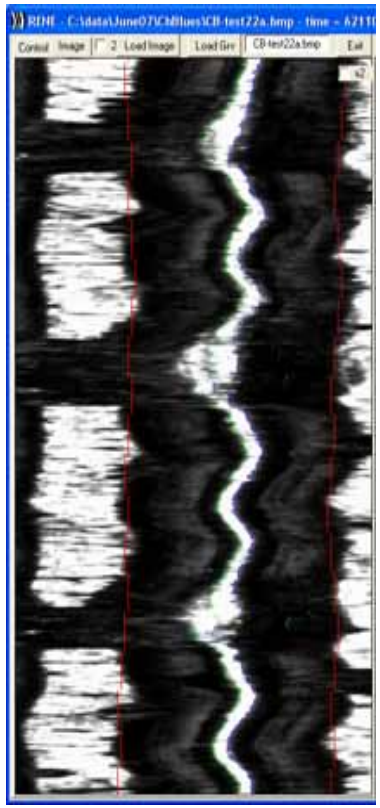




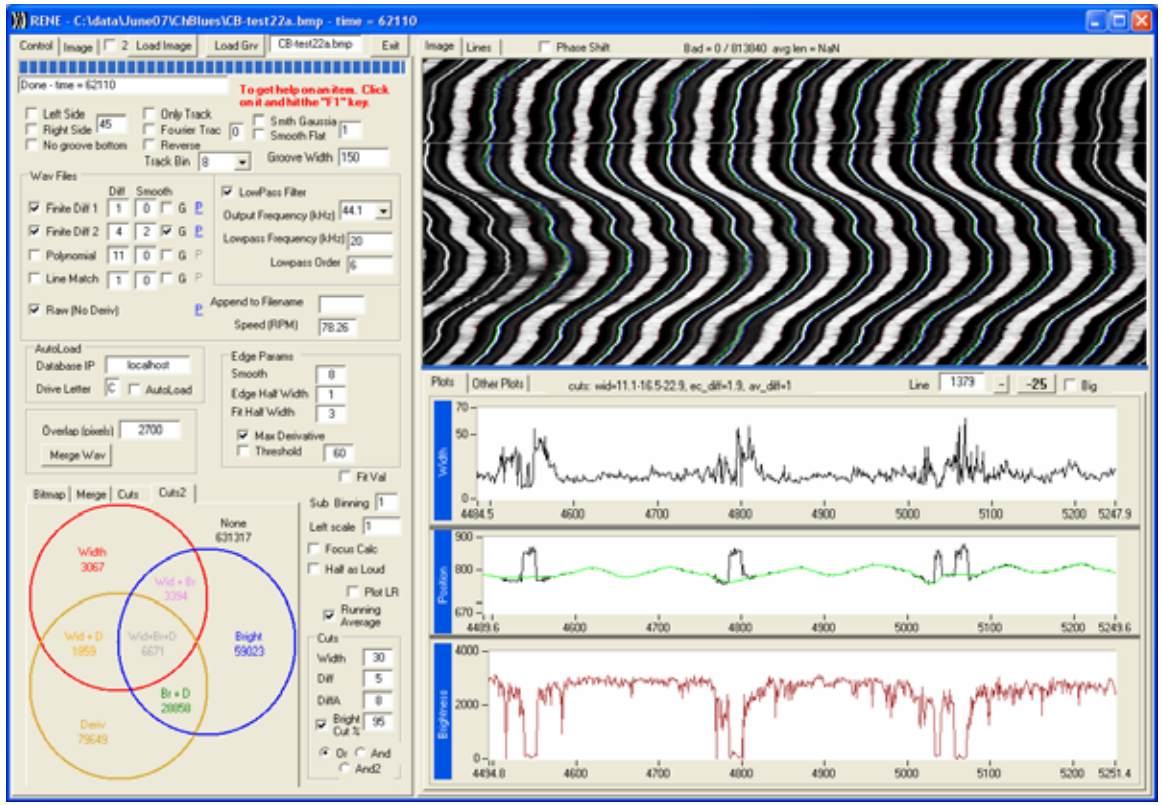
Average
Filter using width cut

Example of IRENE Software

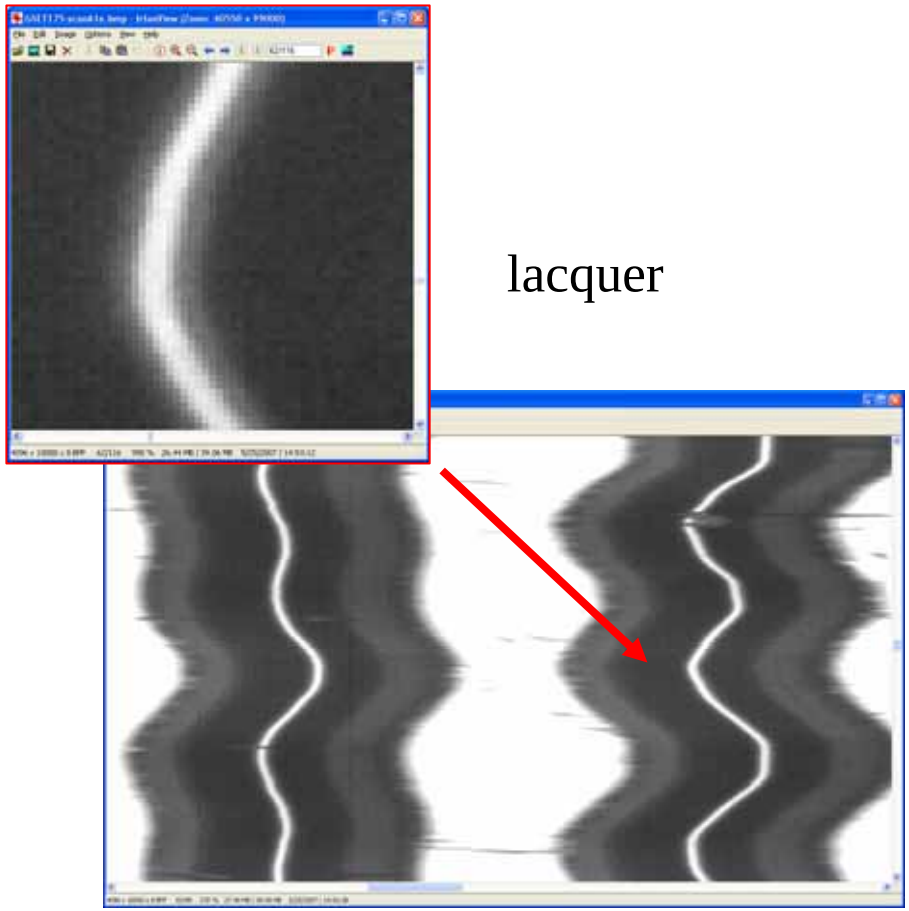
Image View



Control View

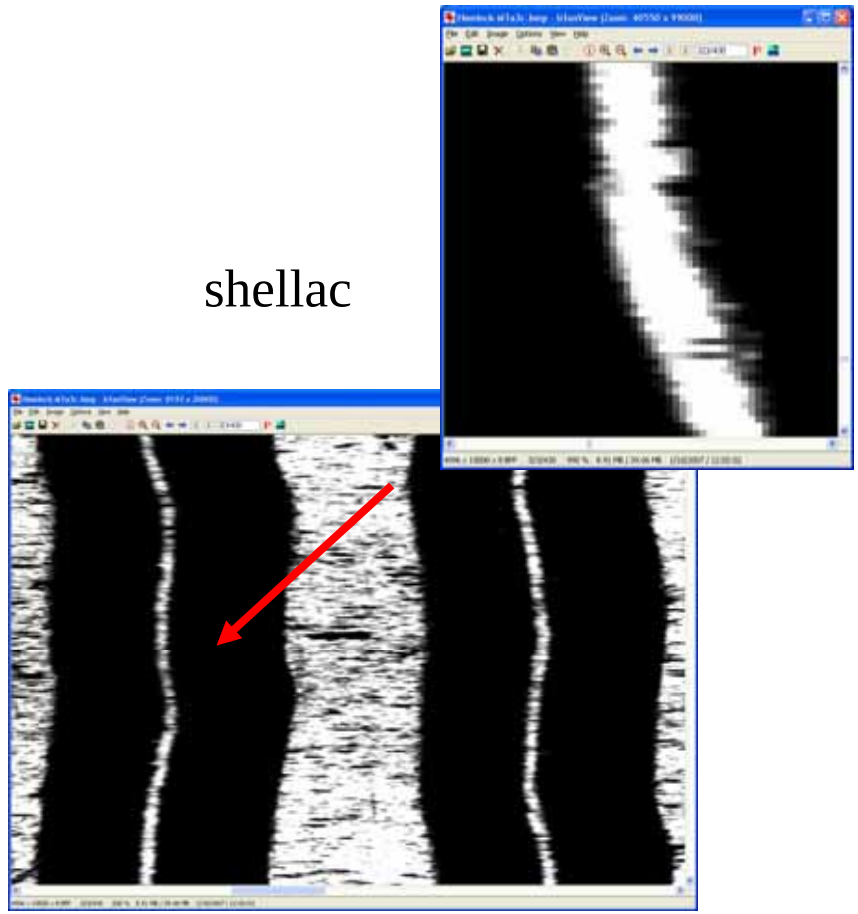


Media Characteristics

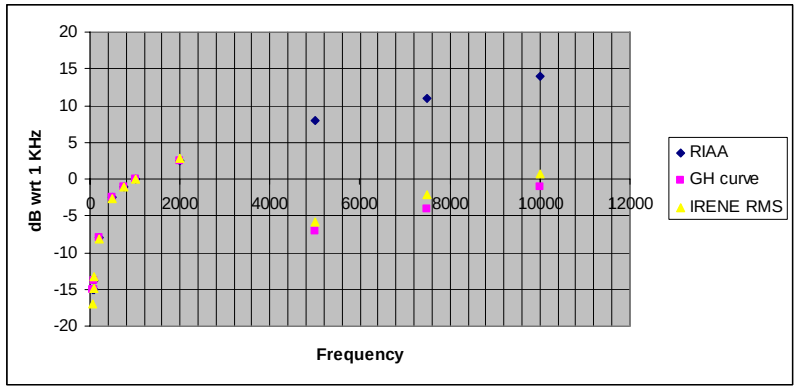


lacquer

shellac



Pristine test disc

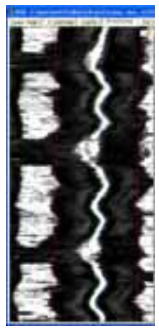


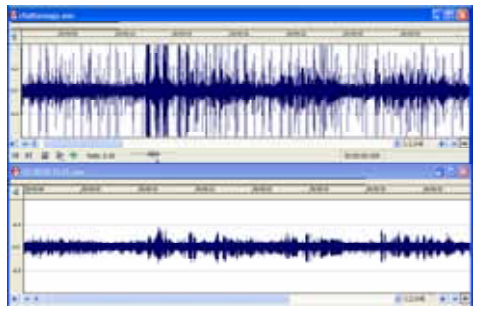
Les Paul 1953

Stylus-skip

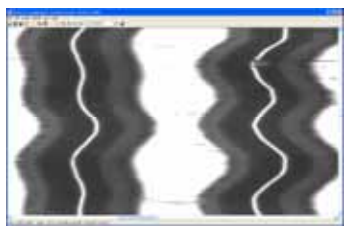
IRENE

Ida Cox 1923 heavy wear



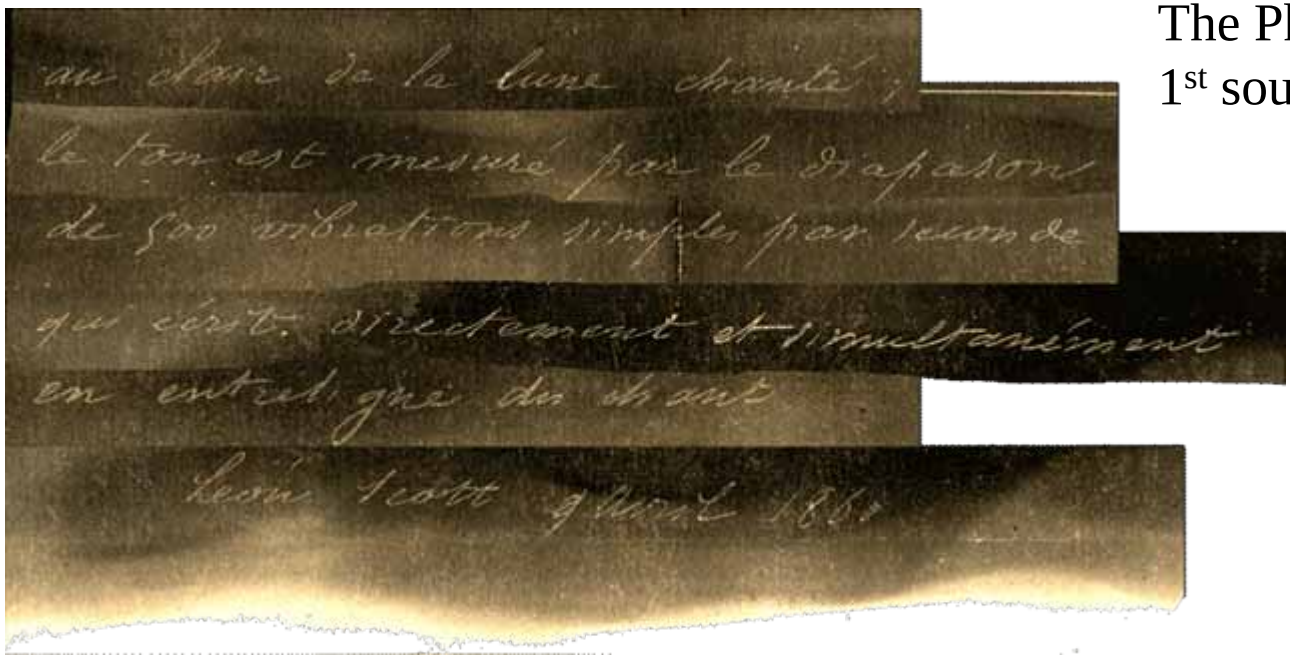


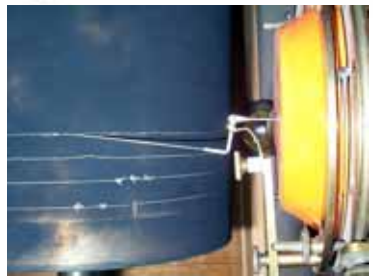
Broken disc
1930



Lacquer radio transcription
1950

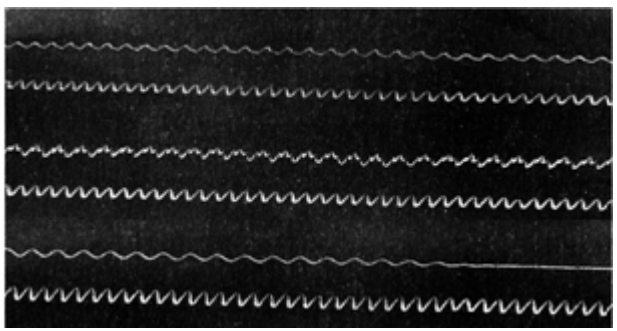
The Phonautograph – L.Scott
1st sound recording in history

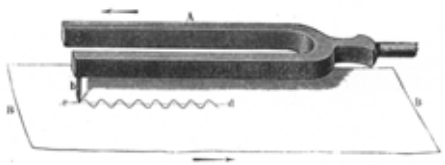

au clair de la lune chanté ;
le ton est mesuré par le diapason
de 500 vibrations simples par seconde
qui écrit directement et simultanément
en entrelignes du chant
Léon Scott 9 Avril 1860



"Au Clair de la Lune" ["By the Light of the Moon"] sung;
"…the pitch is measured by the tuning fork of 500 simple vibrations per second which writes directly and simultaneously in interlinear space of the song"

Léon Scott 9 April 1860





2008

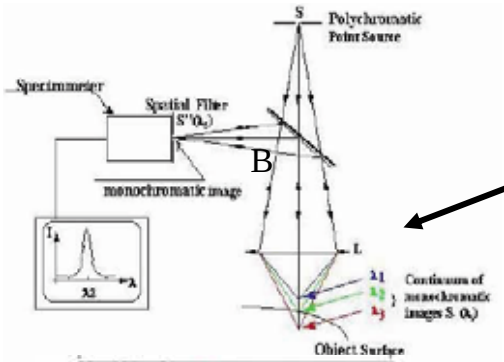
1860

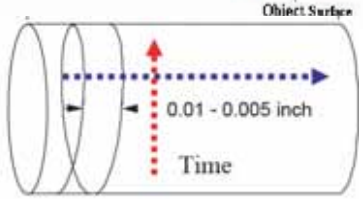
IRENE: Summary and Outlook

- Considerable insight into 2D optical scanning on a wide range of materials
- Particular performance on damaged media
- Good frequency response
- Broad band noise on shellac greater than lacquer, and stylus version, due to imaging response of the media
- 3D scanning will lead to greater redundancy and lower noise levels may be expected
- Key hardware aspects were focus and illumination – still evolving
- Work underway to make IRENE a tool for the archive

3D Scanning Process

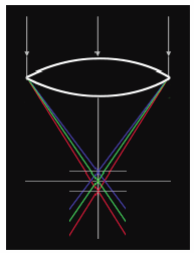
A





D

C



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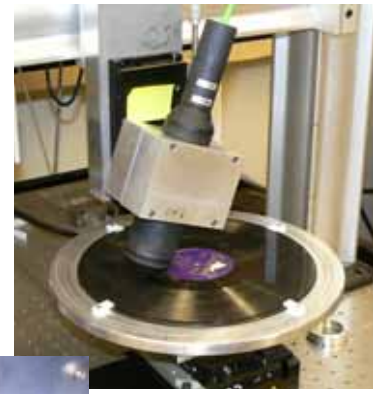

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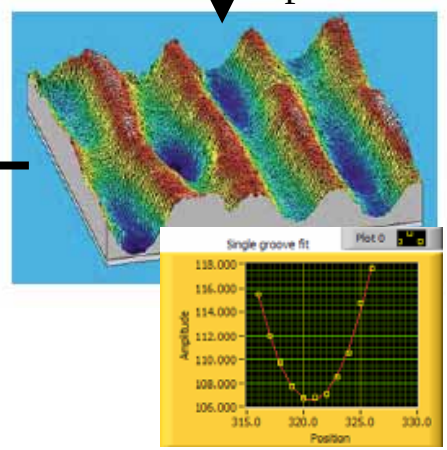

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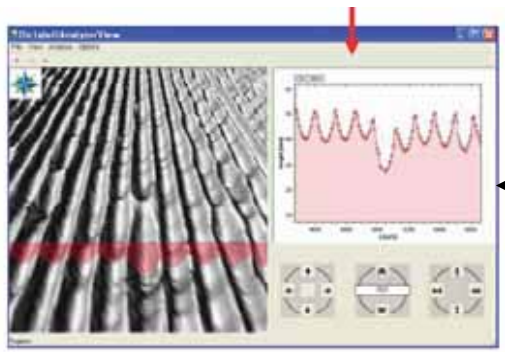

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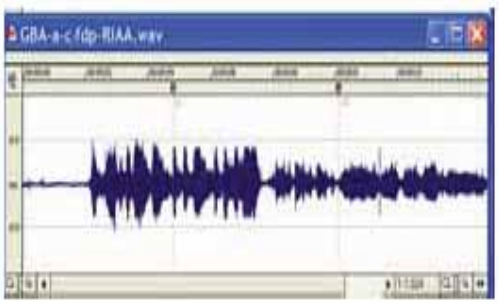
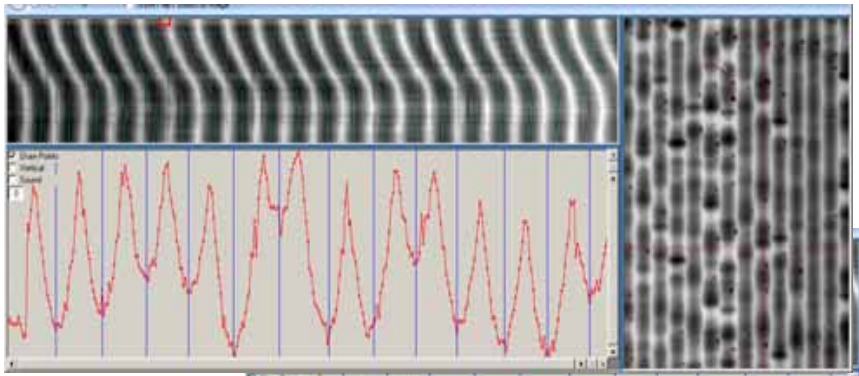
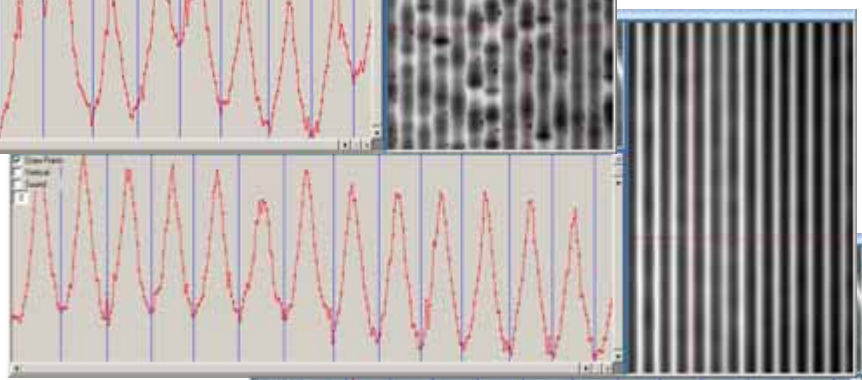


3D Data Analysis

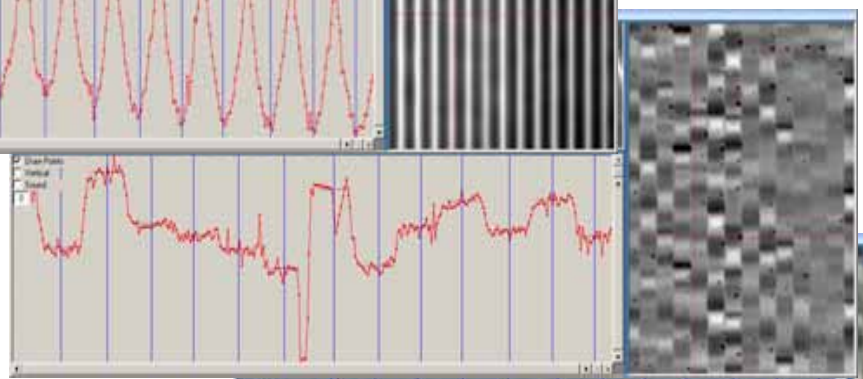


Raw image, greyscale = depth

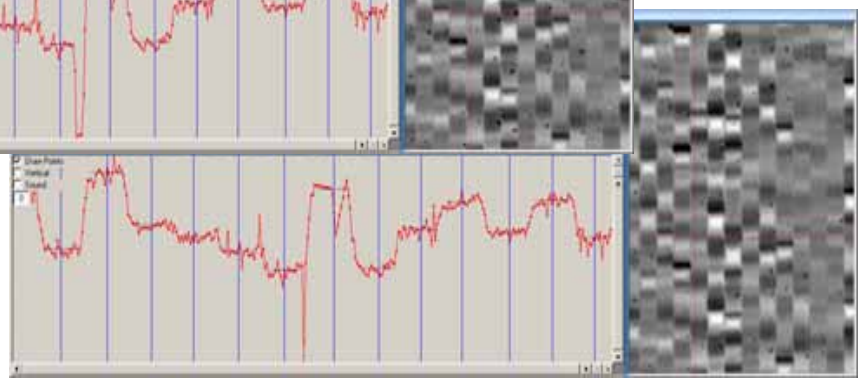


Profile view

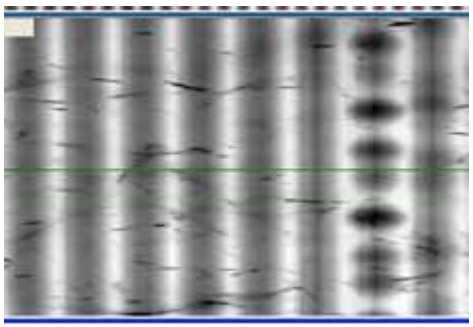
Spatial average to determine local shape



Subtract local shape

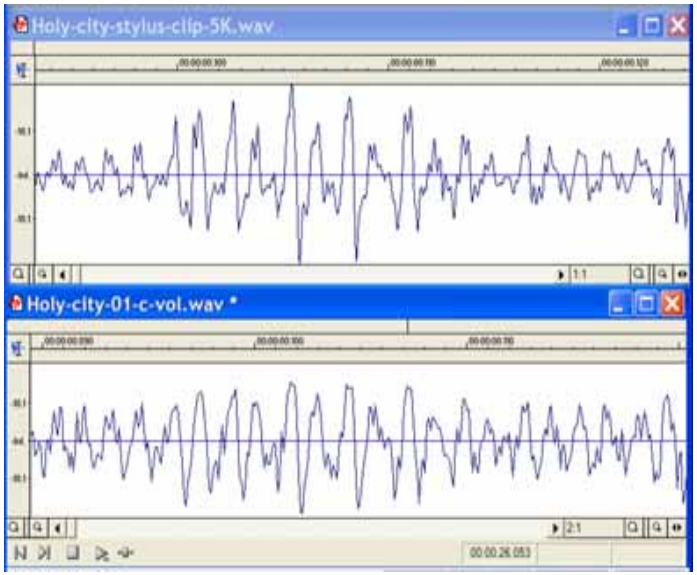


"blobs" removed



Condition assessment

3D Examples

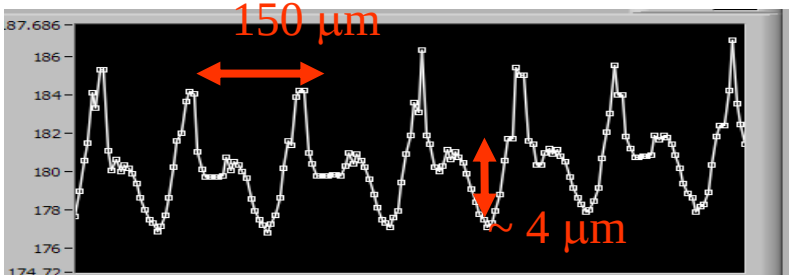


Commercial
Edison cylinder

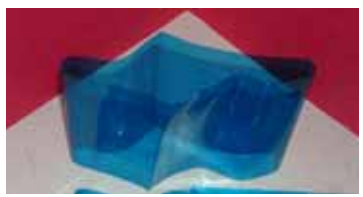
stylus

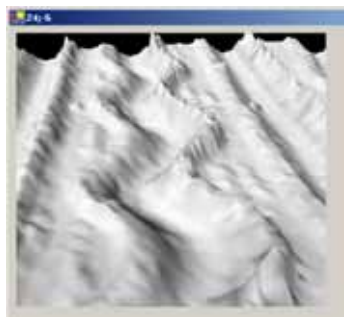
optical

Ishi – Native American fieldwork cylinder 1911, UC Berkeley



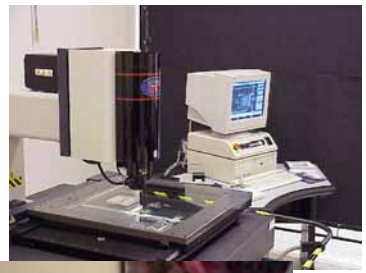
Plastic dictation belt





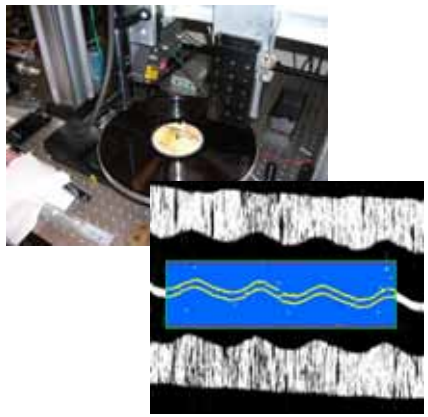
Optical Scanning: Technology Roadmap

Basic **2**D concept demonstration
40 min / 1 sec

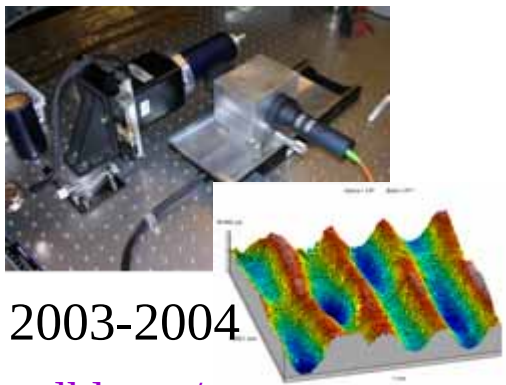


2002

2D disc R&D
4 sec / 1 sec



3D cylinder R&D
20 hr / 1 min



2003-2004

IRENE
System eval

2006-2007

Production mode discs

2008 - ?

3D System
10 min / 1 min

2007-2009

Collections projects

Web site URL: http://irene.lbl.gov/