Imaging the Voices of the Past: New Ways to Digitize Historical Sound Recordings

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What is Sound?

- Matter = gas, liquid, and solid
- Matter can be compressed by a force
- Density = stuff / volume
- Sound
  - Compression = increased density
  - Rarefaction = decreased density
  - Sound is energy which travels through matter via periodic compressions and rarefactions
  - Period = pitch
  - Amplitude = loudness
- We experience the sensation of sound when our ears respond to periodic compressions and rarefactions of the atmosphere (or other media).
Sound Recording

• Sound can be transferred from one material to another
  – Beat a drum
  – Pluck a string
  – Stand near a speaker
  – Speak into a paper cup and feel the bottom vibrate

• Sound can be directly recorded by capturing the mechanical effect permanently in material
Inventions

Phonograph
Leon Scott
1853

Phonograph
Tom Edison
1877

Scott enscribed sound on paper and could not play it back.

Edison embossed sound on foil and was therefore the first to reproduce it.
History

• Scott’s invention was ingenious
• Edison’s invention was transformative
• From Edison onwards the technology of sound recording and reproduction has focused on
  – Improved media
  – Fidelity
  – Capacity
  – Access
Recorded Sound is Valuable

- Technical tests and experiments…
- Field recordings of linguistic, cultural, and anthropological materials…
- Primary recordings of key artists
- Field recordings of sources which underlie much of modern music, American and European folk traditions…
- Speeches & spoken words of historical figures, Edison, Churchill, Roosevelt…
- Early radio broadcasts (lacquers)…
- Live performances, events,…
- Public and private dictation and monitoring records, intelligence, Presidential sources,…
- Commercial record releases…

This is a record of our culture
So how much is there?

- American institutions hold some 5 billion items in their collections
- Of these about 45 million are sound recordings
- Of these about 10 million are mechanical
- **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).
What’s the Problem?

• Archivists want to copy all pre-digital media into modern forms.
• It’s a big project.
• Much of it is in unknown condition.
• Some of the materials are damaged or too delicate to “play”.

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Can science help preserve culture?

• “Preservation Science” supports museums, libraries, and collections through
  – Analysis and processing of materials
  – Dating
  – Imaging and measurement
  – Analysis of images and signals
  – Studying degradation mechanisms
  – Developing information technology tools and resources
Digital is Forever

• A key concept for preservation is digitization
• Digital materials can be copied exactly
• Robotic scanning of texts is in wide use at major libraries, Google…
• Unlike texts, digitization of historical sound recordings is often an invasive process-by definition
A Modern Physics Approach to Sound Recordings

• Could we digitize a recording *without contact* to the medium – *like robotic 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

• Precision optical measurements are widely practiced in the physics research lab
Non-Contact Digital Imaging

- Create a high resolution digital image 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 and delicate records
- Offload aspects of restoration to automated software

A “smart” copying machine for records
What do we need to know?

• What do I want to measure and how well?
• What are the right tools?
• How can I interpret the results?
• How do I know if I am doing a good job?
• Is there a future?
• Who will do the work?
• Who will pay for it?
Mechanical Recording Principles

Cylinder: groove varies in depth (Vertical Cut)

Disc: groove moves from side to side (Lateral Cut)

Vertical cut recording, surface varies locally.

\( \Phi 2.1875 \)

4.000

0.01 - 0.005 inch

groove spirals around cylinder, 100-200 tracks per inch

\( \approx 20 \text{ microns} \)
A human hair is 25-50 microns in diameter.

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

- Digitally **image** the surface
- **Process image** to remove defects
- **Analyze shape** to model stylus motion.
- **Sample** at standard frequency
- **Convert** to digital sound format.
- **Store results** as **standard digital sound files** (.wav) and high resolution **digital images**

Digital imaging technology and data processing are improving significantly year after year, fueled by diverse commercial and scientific applications.
2D Imaging: Electronic Camera

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

Coaxial illumination
3D Imaging: Chromatic Aberration
3D Imaging: Confocal Scanning Probe

Required for cylinder with vertical groove modulation.

Depth resolved to ~0.1 micron
Feature extraction and measurement

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

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What is the relationship between “groove” and sound?

Electro-magnetic case

induction

Acoustic case

Diaphragm is over-damped to provide flat response

Max. Slope = Max. Sound

Amplitude

Wavelength

Sound = Stylus Velocity = Groove Shape Derivative

(“constant velocity condition”)

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1st Test: Does this work?

“Goodnight Irene” by H. Ledbetter (Leadbelly) and J. Lomax, performed by The Weavers with Gordon Jenkins and His Orchestra ~1950

optical readout.

mechanical (stylus)
Projects Underway

• The Library of Congress and other public custodians of cultural history have seen promise in this approach and supported a research program

• “IRENE”: a fast 2D optical scanner for disc records (NEH)
  – Installed 2006 at Library of Congress, evaluation, upgrade

• “3D”: develop a fast 3D scanner for cylinders and discs (IMLS)
  – Funded in 2007 and currently under development

• Special Studies: damaged, broken, unplayable, rare
I.R.E.N.E.
Image, Reconstruct, Erase Noise, Etc

- Bluebird
- 73 mm
- 4.000
- Indicates radial width of 1 sweep
- Direction of azimuthal scan
- Direction of radial scan
- Sensor field of view projected onto surface 1 x 4000 microns
Width across groove bottom

Measure slope at each point (stylus velocity)
Test Discs

Pristine new acetate disc scanned by IRENE
“Johnny”: Les Paul and Mary Ford
1953 recording, shellac 78 rpm disc is worn and scratched, distorted

Stylus version has a clear skip due to scratch

IRENE
Chattanooga Blues 1923
Ida Cox, Paramount 12063

Acoustic recording, heavily worn, cracked, with significant stylus damage and distortion
Broken Record

Gilbert and Sullivan “Iolanthe” 1930 Victor 9708
3D Scanner
3D Data Analysis

Raw image, greyscale = depth

Spatial average to determine local shape

Subtract local shape

“blobs” removed

Profile view

Condition assessment
Sound Comparison

- The Holy City, composed by Stephen Adams,
  The Edison and Skedden Mixed Quartet, Amberol 1601
  Commercial cellulose release

- Stylus
- Optical
Response of horn and diaphragm at low frequency can modify response and deviations from “constant velocity” characteristic.
Native American Field Recordings

UC Berkeley Collection 3000 cylinders
Ishi Recordings: The Story of Wood Duck

Such collections are a valuable tool for scholars and for language preservation programs.

This narrative is ~2.5 hours long and is contained upon 51 wax cylinders.

Sam Batwai, Alfred L. Kroeber, and Ishi
• He built a paper recorder but had no way to reproduce sound.

• Scott deposited the results of his research at the French Academy of Sciences, in Paris. They have remained there, in good condition, for nearly 150 years.

• In 2008 we digitally scanned Scott’s paper recordings in Paris and applied the IRENE analysis.
Paper coated with lamp soot (lamp black)

Recorded April 9, 1860
Deposited in the French Academy of Sciences

Located and scanned in March 2008 by FirstSounds Collaboration
"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
Phonautograms are visually similar to “IRENE” 2D scans and can therefore be processed and analyzed by the same tools… …albeit with much lower fidelity.
Under the moonlight, My friend
Pierrot
Lend me your pen, So I could write a word
My candle is out, I've no more light
Open your door for me, For God's sake.
Under the moonlight, Pierrot replied,
I've no pen, I'm in my bed.
Go next door, I believe they're in,
For in the kitchen, Someone lit a match.

Au clair de la lune, mon ami Pierrot
Prête-moi ta plume, pour écrire un mot.
Ma chandelle est morte, je n'ai plus de feu.
Ouvre-moi ta porte, pour l'amour de Dieu.
Au clair de la lune, Pierrot répondit
Je n'ai pas de plume, je suis dans mon lit.
Va chez la voisine, je crois qu'elle y est.
Car dans sa cuisine, on bat le briquet.
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1st example of a sound recording in history
2nd example of a sound recording in history w/ 500 Hz tuning fork crosstalk

Do Re Mi... in D major
Epilogue

• Edison announced in his invention in 1877 to international acclaim.
• Scott complained bitterly, in print, that the original credit was rightfully his.
• Scott died a year later.
What is the future?

Gifted to the nation by David W. Packard, opened in 2007
Who did the work and who paid for it?

**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

**First Sounds**
Optical Scanning: A general tool to preserve and create access to recorded sound history


Web site URL: http://irene.lbl.gov/
Can I do better in the future?

2002 Basic 2D concept demonstration
40 min / 1 sec

2003-2004 3D cylinder R&D
20 hr / 1 min

2006-2007 IRENE System eval

2008-2009 Pilot study

2008? Production mode discs

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