A Short History of Motion Picture Projection Technology

Lance Hammond

September 8, 2006
http://www.mavam.com/lance
Outline

A tutorial on commercial 35mm projection
  — The optical path
  — The sound path
  — Film handling

A history of film projection
  — Origins and film
  — Picture development
  — Sound development
  — The future?
A Professional 35mm Projector

The key parts of this projector are represented schematically below.
A Short History of Film Projection Technology

Projector Optical Path I

AC Power → Power Supply → DC Power → Xenon Bulb → Light → Changeover Mechanism → Strobed and Timed Light
Projector Optical Path II

Strobed and Timed Light → Small Image → Enlarged Image → Screen

Film → Lens
Projector Sound Path I

A Short History of Film Projection Technology

Projection Tutorial

Soundhead

- Exciter Bulb
- Lens
- Dual Solar Cell

Preamplifier/Processor

- Left Total
- Weak L/R Signals
- Right Total

- Left
- Center
- Surround
- Right

Adaptive Matrix Decoder
Power Amplifiers

Right
Center
Left
Surround

Processed Channel Signals

Digital Delay (several ms)

Auditorium
• Edison invented the first practical camera/projector (~1896)
  — Others were invented elsewhere, but failed quickly
  — Key development: 35mm flexible film stock, developed with Eastman Kodak

• Film has always been the heart of the system
  — Convenient 35mm size has been the primary format from the start
  — Initially cellulose nitrate
    • Reasonably strong and transparent
    • Tends to decay over long periods of time
    • Flammable and sometimes EXPLOSIVE!
  — Switched to cellulose triacetate (“safety film”) in the 1940’s
    • Melts instead of burning
  — Now generally use polyester-based stock (since 1970’s-1990’s)
    • Just slightly better than acetate film in most respects
    • Thinner and stronger than old films — projector breaks first!
Basic Projection History II

A Short History of Film Projection Technology

History: Basics

• Arc lamps have always been the primary light source
  — Come close to simulating daylight colors (high color temperature)
  — Nearly emulates a point source, so it’s easier to focus across a picture
  — First used carbon arc “bulbs” (very maintenance-intensive)
  — Switched to Xenon arc bulbs in the 1940’s

• Film handling has changed slowly
  — 4 perforations per frame sprocket drive has been standard since the start
  — 18–22 fps initially, standardized to 24 fps prior to sound introduction in 1920’s
  — Manual changeover between two projectors was used for features
    • Projectionist must switch projectors every ~20 minutes
    • Films still have pairs of projectionist cues at upper right near reel ends
    • Still used at some theaters, like the Stanford, that rotate films daily
  — Now platters are used to hold entire features
    • Much less labor intensive
      1. Film arrives in cans, like those at right
      2. Original reels are be spliced together with trailers & leaders
      3. Projectionist now just needs to start the feature!
    • No rewinding between shows
    • Trailer changes can be done right on the platter
    • Automation cues can control house lights, sound, etc.
Color Film

A Short History of Film Projection Technology

First attempt: Red gunshots in *The Great Train Robbery* (~1900)

Partial color attempts (~1910–1920’s)
- Additive color processes
  - 2 or 3 colors were shot onto alternating frames of film using filters
  - Projectors combined together while playing — but misalignment was common
- 2-color processes
  - Strips of 2 colors combined onto the same film stock

Technicolor 3-strip process (1930’s–present)
- Film shot to red, green, and blue films simultaneously
  - Color selection done using beam splitting and filtering
  - Shot to 3 film stocks (each basically B/W)
- Prints made by literally printing 3 complement colors onto film
- Walt Disney was the first to use it in *Flowers and Trees* (1932)
- Color is very stable — but misalignment of 3 original negatives is possible over time

Composite color films (1950’s–present)
- C/M/Y emulsions are sandwiched together right in the negative film
- More complex film processing, but can result in more realistic color with good film
- Early composite prints tended to decay unevenly over time
Widescreen I

• Came about in 1950’s as an answer to television

• “Shorter” picture formats
  — Adding sound had reduced the height of the film image a bit, so why not more?
  — Common formats are 1.66:1 (Europe) and 1.85:1 (U.S.)
### Widescreen II

A Short History of Film Projection Technology

#### History: Picture

- **Cinemascope**
  - Twentieth-Century Fox introduced this in the mid-1950’s
  - Compresses picture 2:1 horizontally, uses full frame vertically
  - 2.35:1 aspect ratio in its current form

- **70mm film**
  - 2.2:1 aspect ratio on 2x-wide film, 5-perforation format
  - Ultra-high resolution, but EXPENSIVE, especially due to 6-channel magnetic stereo
  - 70mm projectors can always also show 35mm prints

- **Other formats**
  - Interlocked projectors (expensive and generally impractical)
    - Used today only for some specialized applications
  - VistaVision, sideways 8-perf on 35mm film at 2.35:1
    - Used today for visual effects work (a “poor man’s 70mm”)
  - IMAX film, sideways 15-perf on 70mm film at 1.37:1
    - Common ultra-large format at museums and similar venues
Large Format Comparison

A Short History of Film Projection Technology

35mm Scope

IMAX 70mm

Standard 70mm
Sound History I: Analog Mono

A Short History of Film Projection Technology

• Organ music (1900’s – early 1930’s)
  — Organist played a score timed to synchronize with a silent movie
  — Still happens at the Stanford theater!

• Vitaphone and other manually synced formats (1928 – mid 1930’s)
  — First started with *The Jazz Singer* and *Steamboat Willie* (both in 1928)
  — Projectionist played recorded music / effects at the appropriate time
    • Speech was typically impossible to do well because sync was not close enough
  — “Vitaphone” was a record-based version of this technology

• Monaural Optical Sound-on-Film (mid 1930’s – 1980’s)
  — Sound printed right on the film, alongside the picture, like an oscilloscope trace
    • Picture had to shrink and shift slightly to make room for the soundtrack
    • Prints cost no more than silent ones
  — ~40 Hz – 8 kHz frequency range set by size of early read heads and film speed
  — First read by phototubes, and later by silicon solar cells
  — Became a STRONG standard very quickly
### Sound History II: Analog Stereo

- Disney’s *Fantasia* (1940) was presented using a custom stereo setup.

- **CinemaScope magnetic stereo** (mid-1950’s)
  - 4-channel stereo introduced along with the scope widescreen format
    - Recorded using optional magnetic tracks in place of the normal optical ones
  - Prints were too expensive, so it died quickly

- **70mm magnetic stereo** (late-1950’s – 1980’s)
  - 6-channel stereo
    - Two different speaker formats used (1950’s-60’s and 1970’s-80’s)
  - Very expensive process to add iron oxide magnetic tape tracks to the film edges
  - Prints did not wear well in projectors, and decayed quickly

- **Dolby “A” Stereo** (1977)
  - “4-channel” stereo
    - Uses dual-channel optical tracks to encode 4 channels through matrix encoding
    - Dolby noise reduction and compression used to improve quality and frequency response

- **Dolby “SR” Stereo** (“Spectral Recording,” 1987)
  - Evolutionary enhancement to noise reduction technology used in Dolby “A”
Sound History III: Digital

A Short History of Film Projection Technology

  — Discrete 6-channel stereo sound
  — Printed as a dot pattern between the soundtrack side sprocket holes on film
    • Limited area requires high compression rates (about 10:1)
    • Encoded primarily as compressed-mantissa FP frequency-domain information
  — Adopted as standard sound for DVDs and ATSC digital TV standard

  — Also discrete 6-channel stereo sound
  — Actual sound is recorded on a set of CD-ROM or DVD discs
    • Synced to picture with timecode and serial # printed on film
    • Off-film format allows lower compression rates (less than 3:1)
    • Can also be used easily with 70mm and IMAX film formats

  — 8-channel stereo format, with no home theater equivalent
  — Printed semi-redundantly and offset on both edges of the film using cyan emulsion layer
    • Front channels will play normally even through film damage clear across the film
    • Compression rates similar to DTS format

• Dolby EX surround extension (1999)
  — Extra center rear surround, matrix encoded in left/right surround pair of any digital track
Sound Formats: Speakers

A Short History of Film Projection Technology

History: Sound

Analog Optical Stereo

Early 70mm Magnetic

Later 70mm Magnetic, Dolby Digital, DTS

SDDS
Sound Formats: On 35mm Film

SDDS Soundtrack

Magenta text does not interfere with cyan SDDS soundtrack

Dolby Digital Soundtrack

Analog Soundtrack

Picture Area

DTS Timecode
A Short History of Film Projection Technology

Sound Formats: Readers

- Digital soundheads are mounted on top of the projector

<table>
<thead>
<tr>
<th>Dolby Digital Soundhead</th>
<th>SDDS Soundhead</th>
<th>DTS Timecode Reader</th>
<th>Optical Head with Lens Turret</th>
<th>Analog Soundhead</th>
</tr>
</thead>
</table>

- Analog sound is printed 19 frames before the picture
  — Allowed sound & picture to synchronize before delay circuits were practical

- Digital sound is synchronized with the analog sound
  — It is read early and digitally delayed for an appropriate sync time
The Future: All-Digital Projection

A Short History of Film Projection Technology

History: Future

• A few theaters have been using this technology (since 1999)
  — George Lucas first pushed it into use with Star Wars Episode I
    • Limited resolution at the time: only about 1,024x768
  — Has only expanded slowly since this time

• Only a part of projectors are different from 35mm:
  — Projector has a conventional lamphouse
  — Optical head is similar to a conference room LCD/DLP projector
  — All moving projector parts are eliminated, keeping maintenance down
  — Currently TI’s DLP is the dominant projection technique (http://www.dlp.com)
    • Array of microscopic mirrors that pivot to reflect light through/away from lens
    • Reflective technology allows high contrast ratio (dark blacks)
  — Sony is pushing high-resolution LCD-based technology (SXRD project, www.sony.net)
    • Just like an LCD screen, but with a MUCH bigger “backlight”

• Digital film storage is also a key component:
  — Started out with ad hoc, uncompressed video data on high-density tapes
  — First “standard” digital format only established in 2005 (http://www.dcimovies.com)
  — Current “standard” is Motion JPEG-2000 on RAID arrays (50-300 GB/film)
    • Only limited compression since artifacts are obvious on a big screen
  — Copy protection of stored digital data is key issue for studios
    • Slows standards development and limits distribution formats (drive? disc? tape? Internet?)
The Problems of Digital

• The current business problem
  — *Studios* want digital, because they will save ~$3K per 35mm print costs
    • Wide releases can require over 6,000 prints = nearly $20M just on film prints
    • More flexible: Doesn’t take several weeks to make prints, so can “expand” instantly
  — But theater *operators* are ambivalent
    • Will save money on projectionists and maintenance in the long run . . .
    • . . . but each theater will cost $100K or more to convert, and . . .
    • . . . there’s still no guarantee that today’s projectors won’t be obsolete tomorrow
    • Projectionist unions are fighting to prevent job loss (fewer needed, plus different skills)
  — Solution will probably require studios to help underwrite conversion costs
    • Alternate model: Sponsors could buy projectors in exchange for ads

• A technical comparison against film
  — Digital has a more stable picture
    • No shuttering of light between frames
    • No frame jitter
  — Digital “prints” never get scratched or dirty during playback
    • Big advantage, since one loooooong scratch can ruin an entire 35mm print
  — Additional “sideband” information can easily be included
    • Multiple soundtracks, in different languages
    • Optional subtitles/captions
    • Much like features in today’s DVDs
  — But film still has higher resolution . . .
## Format Resolutions

<table>
<thead>
<tr>
<th>Format</th>
<th>Aspect Ratio</th>
<th>Film Area (mm)</th>
<th>Approximate Resolution†</th>
</tr>
</thead>
<tbody>
<tr>
<td>NTSC/DVD Video</td>
<td>1.33:1</td>
<td>—</td>
<td>720 x 480</td>
</tr>
<tr>
<td>Max. HDTV Resolution</td>
<td>1.85:1</td>
<td>—</td>
<td>1,920 x 1,024</td>
</tr>
<tr>
<td>DLP Projection**</td>
<td>Any*:1</td>
<td>—</td>
<td>2,048 x 1,080</td>
</tr>
<tr>
<td>Silent</td>
<td>1.37:1</td>
<td>25 x 18</td>
<td>3,300 x 2,400</td>
</tr>
<tr>
<td>Academy Sound</td>
<td>1.37:1</td>
<td>21 x 16</td>
<td>2,800 x 2,100</td>
</tr>
<tr>
<td>US Flat Widescreen</td>
<td>1.85:1</td>
<td>21 x 11</td>
<td>2,800 x 1,500</td>
</tr>
<tr>
<td>CinemaScope</td>
<td>2.35:1</td>
<td>21 x 18</td>
<td>2,800 x 2,400</td>
</tr>
<tr>
<td>VistaVision Wide</td>
<td>2.35:1</td>
<td>38 x 16</td>
<td>5,000 x 2,100</td>
</tr>
<tr>
<td>Standard 70mm</td>
<td>2.20:1</td>
<td>48 x 23</td>
<td>6,500 x 3,000</td>
</tr>
<tr>
<td>IMAX 70mm</td>
<td>1.37:1</td>
<td>71 x 53</td>
<td>9,500 x 7,000</td>
</tr>
</tbody>
</table>

† This estimate is based on “average” modern film stocks with approximately 3,400 dpi / 133 dpmm resolution.  
* Different anamorphic lenses can be attached to the projector to emulate various film aspect ratios.  
** Typical resolution numbers for 2006. Smaller projectors vary from 1,280x720 to 1,600x1,200, while 4,096x2,160 has been suggested.