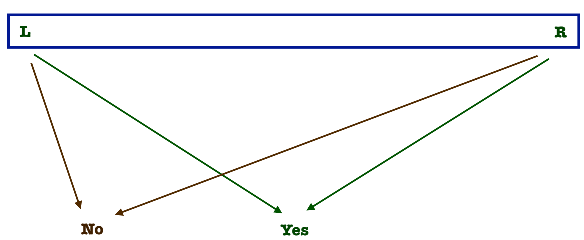
Multi-Loudspeaker Reproduction: Surround Sound

Multi-loudspeaker Reproduction

Understanding Dialog?

Stereo film



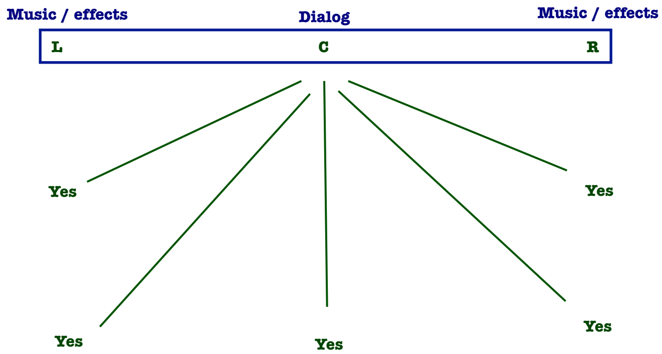
Delay causes echo-like disturbance

Experience with stereo sound for film revealed that the intelligibility of dialog range from good to bad across seating positions.

Multi-loudspeaker Reproduction

Understanding Dialog?

Center Channel

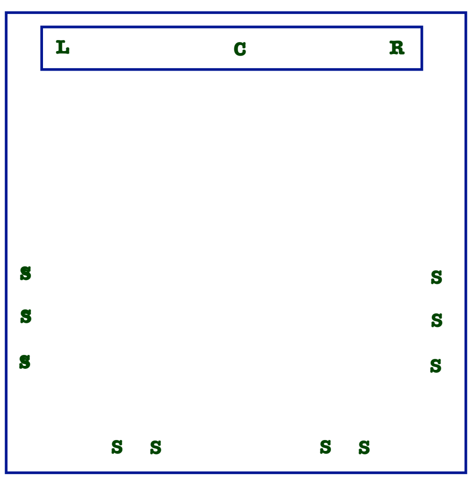


A center channel for dialog provides intelligible speech for all seats even it the dialog doesn't shift right or left with the movement of the character on the screen.

Music and sound effects are able to utilize the left and right channels without problems.

Multi-loudspeaker Reproduction

Dolby Surround Sound (Dolby ProLogic) first surround system standard



Surround Sound

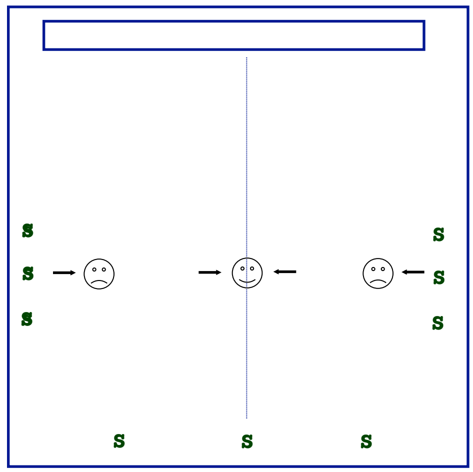
4 : 2: 4

Encode / Decode

- Authored in 4 channels
- Encoded on film or video in 2 channels
- Can be reproduced in 4 channels

Multi-loudspeaker Reproduction

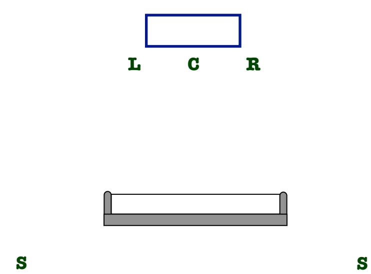
Surround Channel?



Despite the name, a single channel surround didn't produce diffuse soundfield!

Multi-loudspeaker Reproduction

Home Theater Version

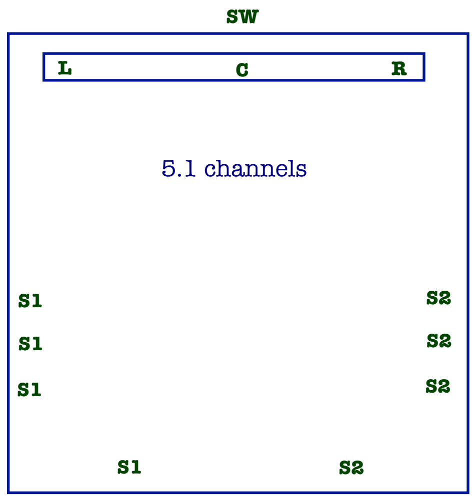


- **Why center channel?**
- **Surrounds still don't work!**
- **Sizing of sound vs. picture!**

Multi-loudspeaker Reproduction

Dolby AC-3 / Dolby Digital

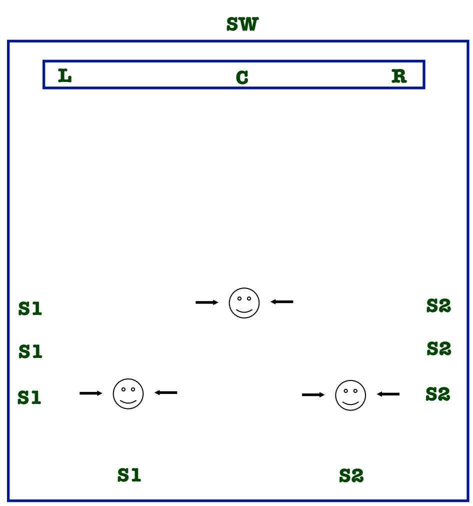
second dominate surround standard



(Subwoofer is low-frequency only)

Multi-loudspeaker Reproduction

Two surround channels can produce a diffuse field!



Much better for Home Theater too!

Multi-loudspeaker Reproduction

5.1 has become an audio standard

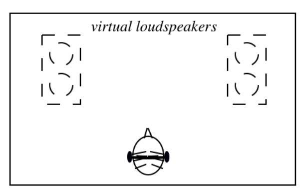
- desktop computer / entertainment
- music forced along!
- How does one reproduce 5.1 source material over headphones or stereo loudspeakers?

Multi-loudspeaker Reproduction

5.1 Reproduction Settings Beyond the Theater

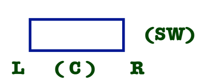
Desktop Systems:

Virtual loudspeakers provide a bridge to headphone and stereo loudspeaker reproduction.

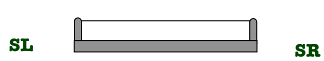


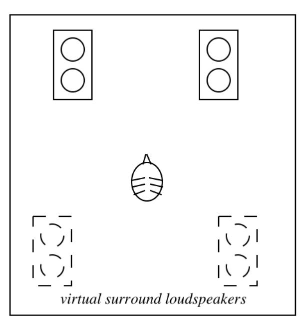
a.

Home Theater Systems



Reproduction can be limited to four loudspeakers





b.

Multi-loudspeaker Reproduction

How well does localization work in 5.1?

"Sound Source Localization in a Five-Channel Surround Sound Reporduction System" Martin, Woszczyk, Corey and Quesnal (1999)

•Phantom image direction evaluated for a home surround sound system.

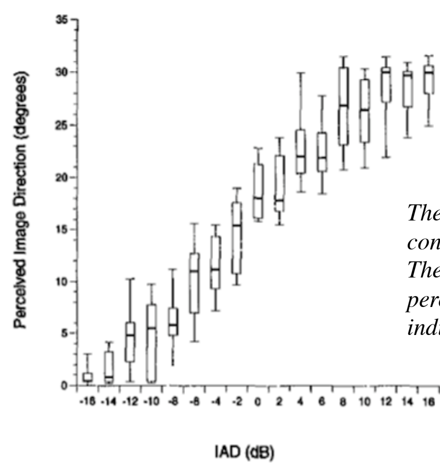
•Both amplitude differences and time delays between adjacent pairs of loudspeakers are evaluated.

•Listener is in the sweet spot.

Multi-loudspeaker Reproduction

Front pairs of adjacent loudspeakers.

Angles for both pairs of front loudspeakers are collapsed onto one range from 0- to 35-degrees.



The range of responses is contained within the whiskers. The box contains the 50th percentile. The median is indicated within the box.

Figure 4 : Perceived direction to phantom image vs. interchannel amplitude difference.
Front pair of adjacent loudspeakers

Multi-loudspeaker Reproduction

Front pairs of adjacent loudspeakers.

Using interchannel time difference!

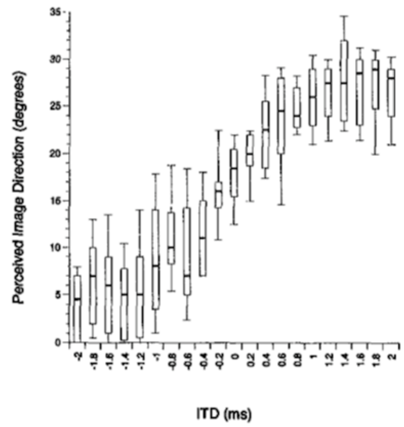
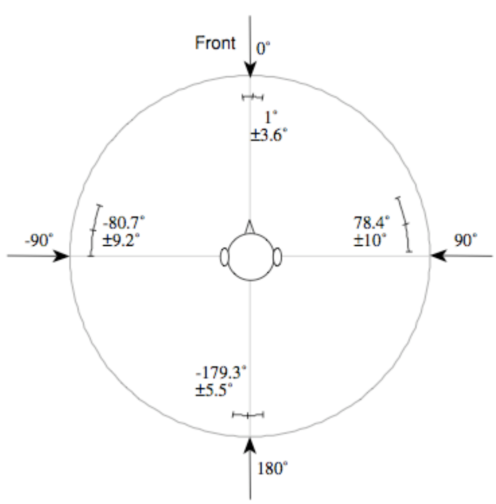


Figure 5 : Perceived direction to phantom image vs. interchannel time difference. Front pair of adjacent loudspeakers

Multi-loudspeaker Reproduction

Remember localization blur!



Multi-loudspeaker Reproduction

Side pair of adjacent loudspeakers.

Angles for both sets of side loudspeakers are collapsed onto one range from 20- to 130-degrees.

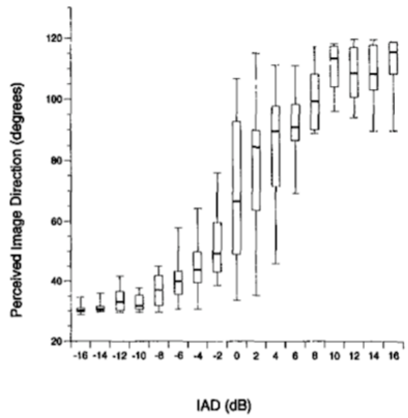


Figure 6 : Perceived direction to phantom image vs. interchannel amplitude difference. Side pair of adjacent loudspeakers

Multi-loudspeaker Reproduction

Side pair of adjacent loudspeakers.

Angles for both sets of side loudspeakers are collapsed onto one range from 20- to 130-degrees.

Also, produced timbral coloration due to combing

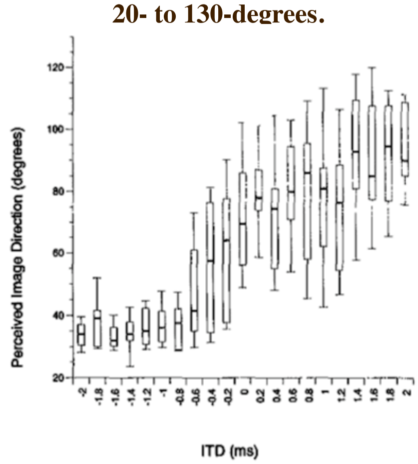


Figure 7 : Perceived direction to phantom image vs. interchannel time difference. Side pair of adjacent loudspeakers

Multi-loudspeaker Reproduction

Rear pair of adjacent loudspeakers.

Angles for rear loudspeakers are in the range from 80- to 280-degrees.

Also, rear images appeared closer to the head both with amplitude and time differences.

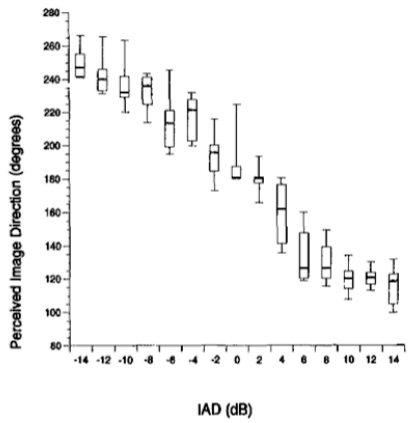


Figure 8 : Perceived direction to phantom image vs. interchannel amplitude difference. Rear pair of adjacent loudspeakers

Multi-loudspeaker Reproduction

Rear pair of adjacent loudspeakers.

Angles for rear loudspeakers are in the range from 80- to 280-degrees.

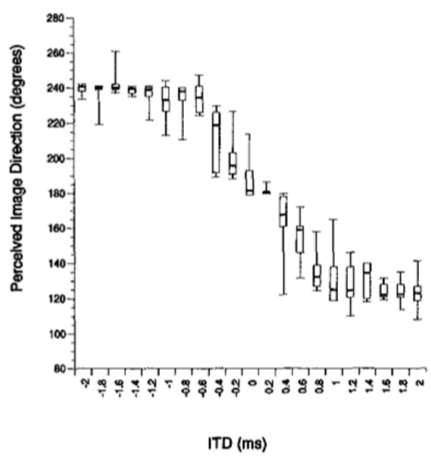


Figure 9 : Perceived direction to phantom image vs. interchannel time difference. Rear pair of adjacent loudspeakers

Multi-Loudspeaker Reproduction: Surround Sound

Multi-loudspeaker Reproduction

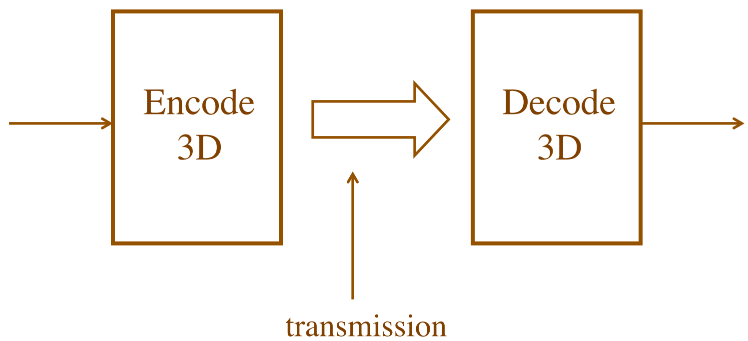
Some current issues:

•Can sound material be authored in a single format for headphones, near-field loudspeakers, and surround sound?

•How should music be mixed for 5.1 reproduction?

Multi-loudspeaker Reproduction

How would a general purpose system be designed?



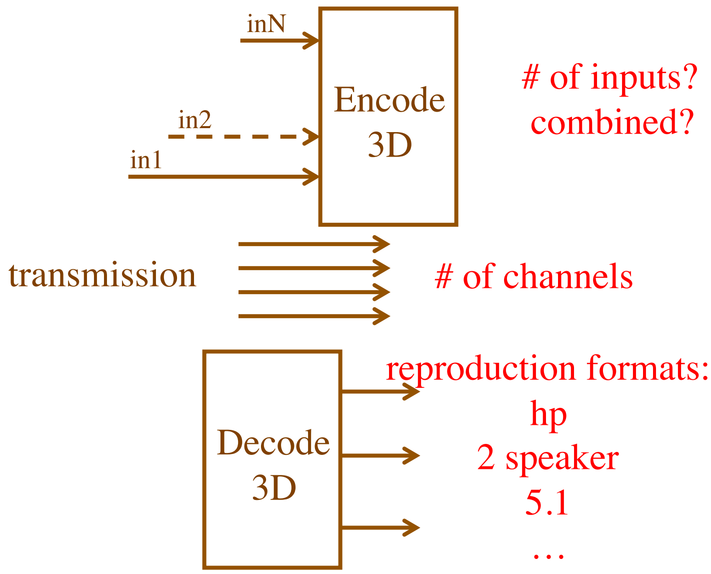
Multi-loudspeaker Reproduction

Jot, et. al article compares and evaluates alternative systems attempting to use objective criteria, though not perceptual criteria:

- Panning
- HRTF techniques
- Ambisonics

Multi-loudspeaker Reproduction

What are the key issues?



Multi-loudspeaker Reproduction

What are the potential tradeoffs?

- fidelity
- timbre
- direction
- # of channels
- listener freedom

Multi-loudspeaker Reproduction
Ambisonics

Gerzon "Ambisonics in Multichannel Broadcasting and Video"

Originally conceived of as an alternative to quadraphonic sound (especially an alternative to stereo-encoded quad) Ambisonics is actually an encode method that is independent of the number of output channels and a decode method that is adaptable to reproduction with an arbitrary number of loudspeakers.

Techniques were pioneered by **Michael Gerzon**, Mathematical Institute at Oxford, and P.E. Fellgett, University of Reading.

Duane Cooper, University of Illinois, deserves some credit for establishing precedents.

Multi-loudspeaker Reproduction
Ambisonics

Ambisonic formats:

B-Format - 4 channels with sum and differences (We focus on this)

Originally conceived in connection with recording with the soundfield microphone.

Multi-loudspeaker Reproduction

Ambisonics

Ambisonic formats:

UHJ - 4 channels with hierarchic encoding for scaled reproduction

G-Format - no decoder

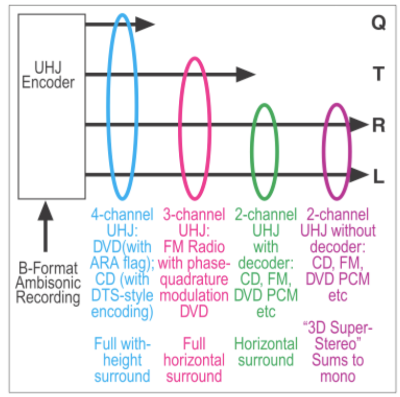


Fig 6. UHJ is a hierarchical surround encoding scheme which allows a surround signal to be experienced at the highest level according to the number of transmission channels available. A single mix satisfies all the available modes without compromise.

Multi-loudspeaker Reproduction

Ambisonics

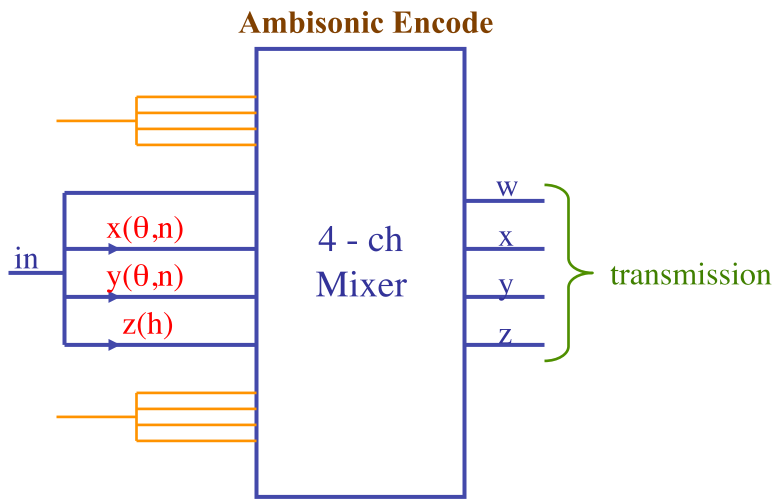
First-order ambisonic encoding

$W = S$	**Source Sound**
$X = S.x = S\sqrt{2}\cos\theta\cos\phi$	**Front-Back**
$Y = S.y = S\sqrt{2}\sin\theta\cos\phi$	**Left-Right**
$Z = S.z = S\sqrt{2}\sin\phi$	**Elevation**

Where θ is azimuth and ϕ is elevation

Z is used for elevation, but when there is no elevated loudspeaker, it is omitted for a 3-channel 2D Ambisonics

Multi-loudspeaker Reproduction



Multi-loudspeaker Reproduction

Ambisonics

Second-order ambisonic encoding

Enables greater specificity in the spatial resolution

For horizontal plane add the following:

U = S cos (2θ) cos ø
V = S sin (2θ) cos ø

Multi-loudspeaker Reproduction

Ambisonics

Ambisonic Decoder

For an N-channel first-order decoder with a regular loudspeaker geometry:

$$\mathbf{S_i = g_i\, S = 0.5\, [\, k_0\, W + k_1\, X \cos\theta_i + k_1\, Y \sin\theta_i\,]}$$

For large-space reproduction, k_0 and k_1 are the same:

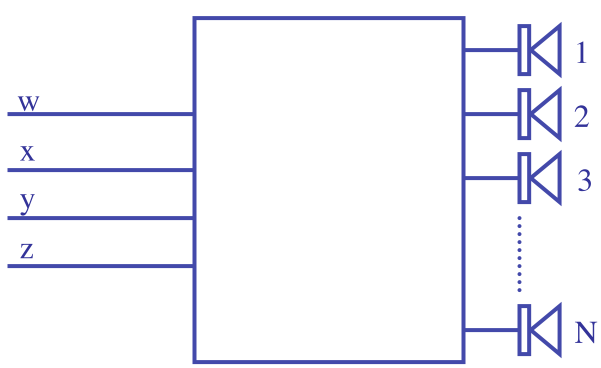
$k_0 = k_1 = \text{sqrt}(8 / 3N)$

where N is the number of loudspeakers

Other loudspeaker geometries can be calculated!

Multi-loudspeaker Reproduction

Ambisonic Decode



Multi-loudspeaker Reproduction

Ambisonics

Soundfield rotations: