Università di Milano
3D VideoGames 2020/2021

3D Game Audio (notes)

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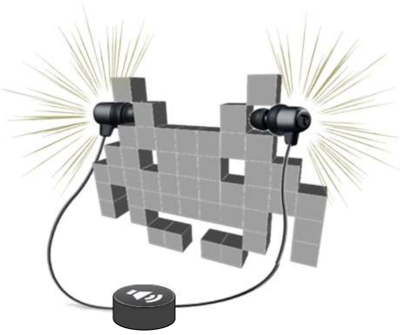

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Course Plan

lec. 1: Introduction ●
lec. 2: Mathematics for 3D Games ●●●●●
lec. 3: Scene Graph ●
lec. 4: Game 3D Physics ●●● + ●●◖
lec. 5: Game Particle Systems ◗
lec. 6: Game 3D Models ●◖
lec. 7: Game Textures ◗●
lec. 8: Game 3D Animations ●●●
lec. 9: Game 3D Audio ●
lec. 10: Networking for 3D Games ●
lec. 11: Artificial Intelligence for 3D Games ●
lec. 12: Game 3D Rendering Techniques ●●

For a much more in-depth discussion of many of the subjects of this lecture, see the course «Sound in interaction»

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Game Audio: intro

- Fundamental aspect of game-design
  - Impact cannot be overestimated
    - for immersion
    - for emotion
    - for gameplay
    - for story-telling
  - (remember that we don't focus on game-design aspects in this course)
- The main technical aspects of game sound are, however, quite unsubtle

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Audio in games: game-design point of view

- Sound effects
  - authored by: Sound Designers / Foley
  - *informative function*
- Ambient sounds
  - authored by: Sound Designers / Foley
  - *immersive function*
- Voiceovers
  - authored by: Dialog writers + Voice actors
  - *narrative (=story-telling) function*
- Music / Score
  - authored by: Composers
  - *emotional function*

e.g.:
dialogs (linear / non-linear)
commentary (non-linear)
narration (linear)

*"Sound makes it **real***
*Music makes you **feel**"*

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Audio in games: game-design point of view

- Sound effects are super informative
  - effective way to make things clear to the player.
  - examples:
    - out of ammo:
      - gun just doesn’t shoot → wrong key? a bug?
      - gun goes “click” → player gets it
    - doors closes *behind* player in 1^{st} person view
      - sound door-slam effect: let him know!
  - can substitute / abstract animation. Examples:
    - character collects object
      - object just disappears from scene → cheesy
      - pick-up animation? → hard to do right, delay affects gameplay
      - add pick-up sound instead (abstract) → acceptable
    - character changes outfit (RPG)
      - just swap character models → cheesy
      - add cloth undressing/dressing sound (abstract) → acceptable

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Audio in games: dev-team roles

- Composer
- Sound Design
- Foley
- Sound Integrator
- Audio Programmer
- Tool programmer (for audio related tasks)

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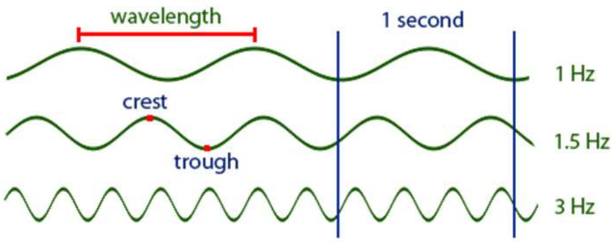
Sound wave

- Air pressure as a function of time
- frequency : (1/sec = 1 Hz)



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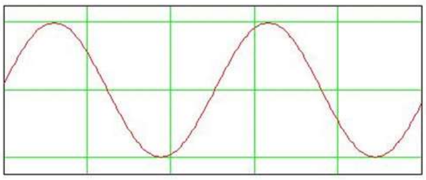
Sound wave

- Air pressure as a function of time
- Waves:
  - frequency (Hz, audible = ~32 to ~16K),
  - amplitude (→ "volume", level, perceived loudness)



- Perception
  - as with most senses, sensorial response is roughly logarithmic with physical quantity
    (e.g.: decibel for amplitudes, notes for frequencies)

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Sound wave & perception 101

What it is: *physical property of the sound wave*	*What it is perceived like:* *by the human hearing system*
Amplitude (crest-to-trough, or crest-to-crest)	Level or loudness (colloquially, Volume) how loud the sound is
Frequency (1/wavelength)	Pitch how high-pitched or low-pitched the sound is *[Ita: acuto o grave]*

logarithmic →

← *exponential*

Spectrum (which frequencies are present)	Timber, tone

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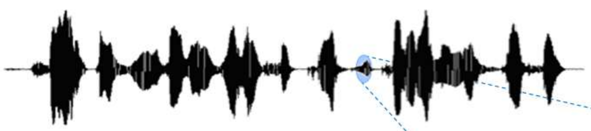
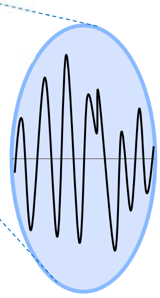
Sound wave as assets

- Air pressure as a function of time



- To digitalize it ("PCM"):
  - sample it
    - at some fixed rate
    - typically, 24-48 KHz
  - quantize samples
    - at some fixed precision
    - typically, 14-24 bits per sample
  - then maybe compress it



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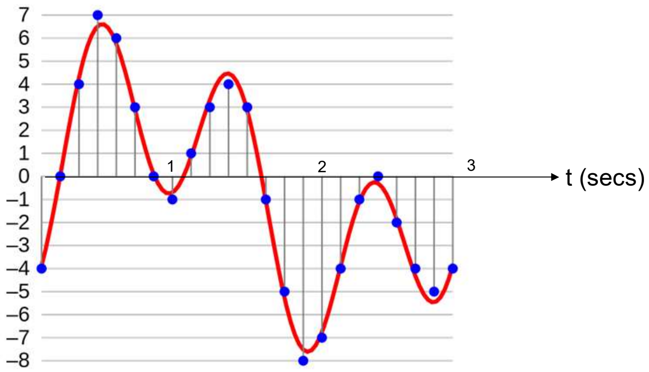
PCM – Pulse Code Modulation

- Toy example: 8 Hz sampling, 4 bit quantization:



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Sound as assets: compression

- PCM (pulse-code modulation)
  - uncompressed: just sampled and quantized
- ADPCM («Adaptive», «Differential» PCM)
  - one way to compress PCM
  - stores 4-bit *prediction errors* (in place of 16-bit values)
  - fixed-compression rate: 4:1
  - fast (on-the-fly, HW supported) decompression
  - not very good compression / quality rate
- MP3
  - works great
  - one example of perceptual encoding
  - needs de-compression *before* it is played

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Assets for sounds: most common file formats

- .mp3
  - perceptual encoding
  - good balance between compression-ratio / quality
  - most common mass-storage format
- .ogg (vorbis)
  - optimized for music
  - usually best quality for compressed
- .wav
  - uncompressed (PCM)
    - not much used as assets (e.g. unity will compress them)
  - or, compressed (ADPCM)

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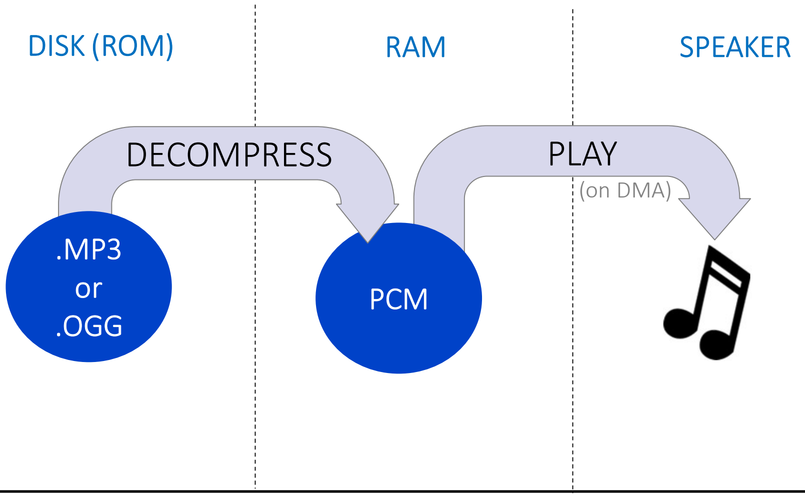
Sound as assets: Life cycle

“Decompress on load”



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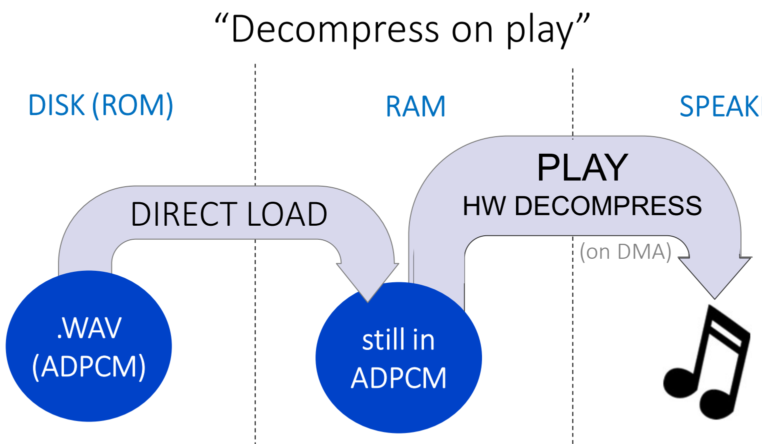
Sound as assets: Life cycle



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Sound as assets: Life cycle

- Static Load «load first, then play as needed»
  - the good: immediate play
  - the bad: costs RAM (good for small / few sound fxs)
  - variant: decompress on Load
    - costs *even more* RAM
  - variant: decompress on Play
    - requires HW support
    - only ADPCM compression (poor ratios or poor quality)
- Dynamic Load «when you need: load, then play»
  - the good: saves RAM
  - the bad: audio-latency (audio-lag)
  - variant: streaming «when you need, play *as* you load»
    - using audio buffer (small dedicated memory, FIFO)

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compare: ADPCM – audio compression, with: DXT (aka S3TC) – texture compression

- unlike more sophisticated compression schemes (e.g., MP3 , JPEG respectively), they are designed for fast, on-the-fly decompression
  - so, data can be kept compressed in RAM
  - decompress on *USE*
  - hardware decompress → hardwired decompress algorithm
- the same price is paid:
  - poor compression rates
  - *fixed* compression rates – no adaptivity
    - compressed size does not depend on content
  - lossy – and very much so
    - poorer quality compared to alternatives
- similar considerations / choices apply, for example:
  - way 1: employ that compression on disk → fast/direct asset loading
  - way 2: employ a better compression scheme on disk → cheaper on storage / bandwidth, but requires decompression and recompression on loading

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Latency in audio: perceptually crucial

- Latency is crucial in audio synchronization
  - Multimodal: audio VS not audio
    e.g., VS video, tactile (keystroke) VS audio)
  - Monomodal: audio VS audio
    e.g., sound effect *1* VS sound effect 2
- max tolerated latency for video *(e.g., "60ms is too much")*
  >>
  max tolerated latency for audio *(e.g., "5ms is too much")*
- Known (empirically) to degrade experience *a lot*
  - True for games, VR, movies…

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Specialized assets for music

- Store a digital *score* instead?

the digital equivalent of this ↑ :
an asset describing which notes
are to be sung during which interval,
with which instrument,
effect (*crescendo*, *staccato*) etc.

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Specialized assets for music

- Store a digital *score* instead?
- The *traditional* music asset in games
  - any classic game tune you can remember was originally stored in this way
    - (think Pacman, Super Mario Bros, Tetris, …)
  - the only way – until the ’90
- Example file format: MIDI
- Pros:
  - much cheaper to store — what used to make this a strict necessity
  - perfect for procedural music — makes this still attractive today (a bit)
    - (e.g. non linear soundtrack)
- Cons:
  - requires instrument library (samples) at runtime
  - limits expressiveness — made this almost abandoned today
    - (e.g. voice, choir, subtleties)
  - limits authoring procedures

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Assets for music today

- Music as just another sampled sound wave
  (as any other audio)
  - maybe looped
  - maybe non-linear
- Typically made of «stem» (sub-tracks)
  - «bass» stem
  - «guitar» stem
  - «choir» stem ...
- Way 1: pre-mix all stems and just bake the result
- Way 2: keep stems separated, mix in realtime
  - more resource consuming (computation/RAM)
  - but useful for re-tuning and non-linear music
    - because some degree of deprecedurality is often needed

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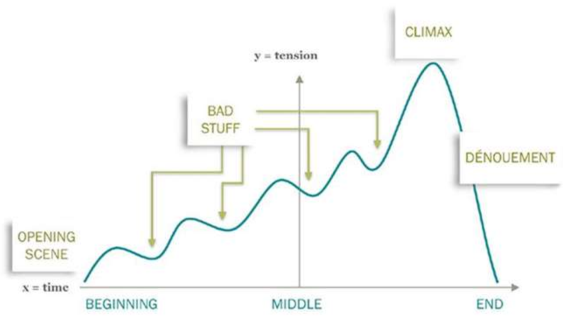
Sound-track: why some degree of *procedurality* is needed in games



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Specialized assets for Ambient Sounds

- Ambience track (“drone” – from *ita*: bordone)
  - the old-school way: just a sound asset (not specialized)
  - looped and long (e.g., ~10 min)
  - typically, low-pitch
  - problems: heavy (long!), repetition artifacts
- Better way: procedural blend of individual FXs
  - according to customizable randomized rules
  - e.g., randomized repetitions, at randomized times
- Authoring: specialized game tools
  - e.g., see http://rpg.ambient-mixer.com/
- Still no standardized asset format for this :-(

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Specialized assets for Ambient Sounds

Example:

- Instead of a Drone loop for:
  - a street traffic scene
  - a jungle
  - a computer room
- Use a random blend of:
  - car horns, engines
  - animal noises
  - individual beeps

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Middleware for sounds in games

oculus

fmod

Resonance Audio
by Google

STEAM AUDIO

Libs: OpenAL , Wwise …

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Sound Rendering: *basic* playback tasks

Main Asset:

the sound buffer

the digitalized sound wave, ready to be sent to the speaker

in any game, even in a 2D setting

- Mixing
  - Linear combinations of waves
  - E.g.: cross-fade 2 sound, maybe with transition functions etc.
- Tweak / Tune: (useful to randomize sounds – e.g., footsteps!)
  - Level (~"loudness") – amplitude scaling
  - both pitch and speed – time scaling
  - *only* pitch, or *only* speed (a bit less trivial)
- Sound filters
  - convolutions of sound buffer
  - useful to add procedural effects as reverb, echos…
- Prioritization
  - why: limited «polyphony» -
    the engine can mix only up to n sounds (e.g., n = 64)
  - solution: game-dev assigns a priority to each sound fx

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Sound Rendering in 3D games
3D (or, "spatialized") sound

- sounds which are:
  - emitted from a virtual source (somewhere in 3D)
  - received from a virtual microphone (somewhere in 3D)
  - propagated across the 3D scene
- useful abstractions used in games:
  - the listener
  - the source(s)

  } sitting in nodes of the scene graph!

note: position and orientation

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3D (or, "spatialized") sound: for direct sound propagation

- consequent auto-tuning of
  - level: (linked to perceived "loudness") according to source-listener distance
    - with a given (dev-controlled) «roll-off» function
    - E.g. $1/d$ or $1/d^2$
  - pitch: (Doppler effect) according to relative speed or source w.r.t. listener
  - interaural time difference (ITD): difference of sound arrival time between the two ears. Used by brain for sound localization Gives illusion of sound relative location w.r.t. head using stereo speakers. It's SMALL! e.g. *~10 µs*

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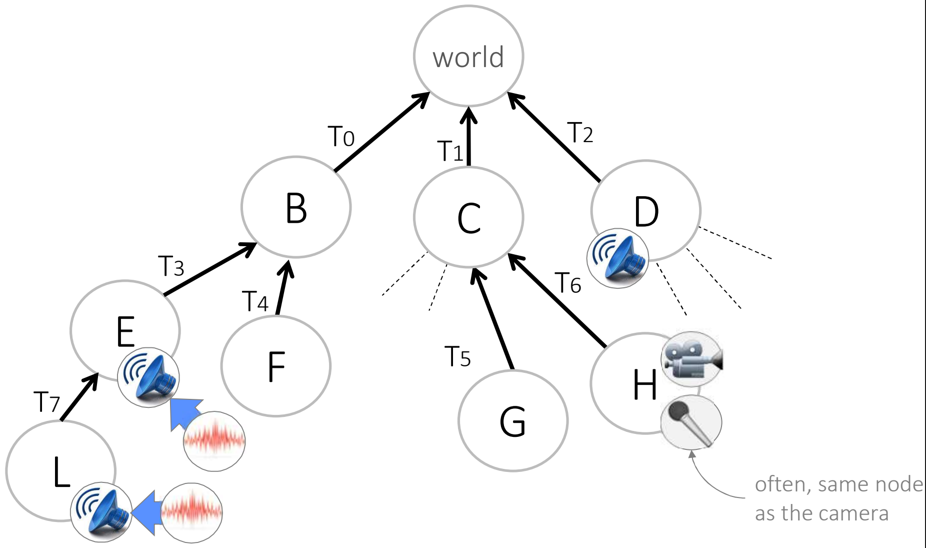
3D (or, "spatialized") sound



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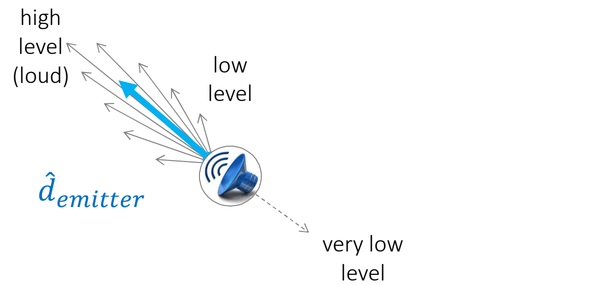
Directional (anisotropic) sound emitters



direction of emitter
(i.e., z-axis of emitter space)

versor
from emitter to listener

- Level = fall-off function of ($\hat{d}_{emitter} \cdot \hat{d}$)

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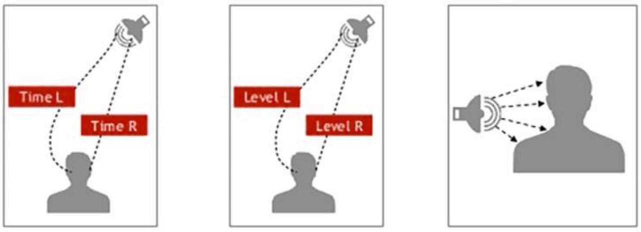
Listener *orientation* is also important



interaural time difference | interaural level difference | anisotropic spectral cues

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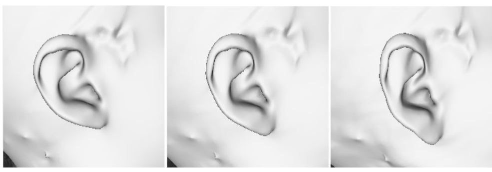
Anisotropic spectral cues for personalized ear shapes (advanced task!)

- Spectral clues: an "anisotropic" stereo sound filter which depends on sound incoming direction
  - in listener reference frame (listener orientation counts!)
- Requires a 3D model of the hear of the listener.



- More commonly, approximations are used

"Reconstructing head models from photographs for individualized 3D-audio processing"
M Dellepiane et al, CGF 27 (7) - (Pacific Graphics)

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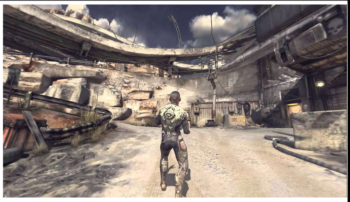
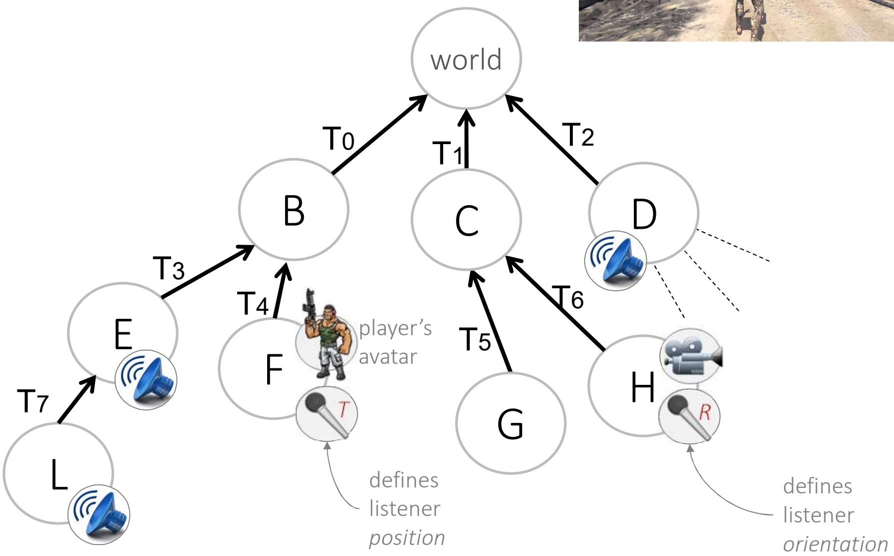
The case of 3rd-person view





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Sound Rendering: sound propagation in the 3D scene

- So far, we only considered the 3D effects of sound direct propagated from emitter to microphone
- In reality, sound-waves interact with solids in the 3D scene
- Three basic phenomena:
  - Absorption: some* energy of the sound-wave is lost (dissipated into heat)
  - Reflection: some* part of the sound-wave bounces off (e.g.) walls
  - Transmission: some* part of the sound-wave passes through solid objects

* *how much of it?* It depends on the materials, and the wave-length

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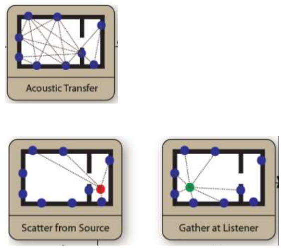
Sound Rendering:
sound propagation in the 3D scene

- Reuse collision proxies!
- Targets simulation of effects by:
  - Absorption (occlusion, obstruction)
  - Transmission (muffling)
  - Reflections (reverb, echoes)
- Active reseach topic
  - Currently: no standard solution adopted by 3D games
  - Often, tricks coded *ad-hoc* by the sound programmer



E.g. see: "Interactive Sound Propagation using Compact Acoustic Transfer Operators"
Lakulish Antani, Anish Chandak, Lauri Savioja, Dinesh Manocha
SIGGRAPH 2012

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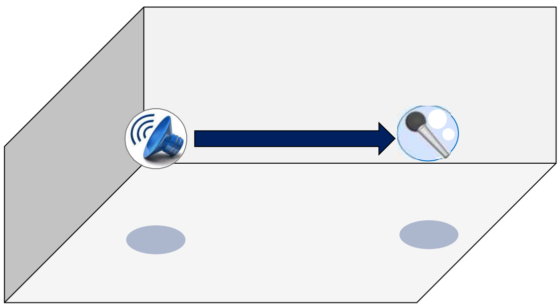
Direct sound propagation



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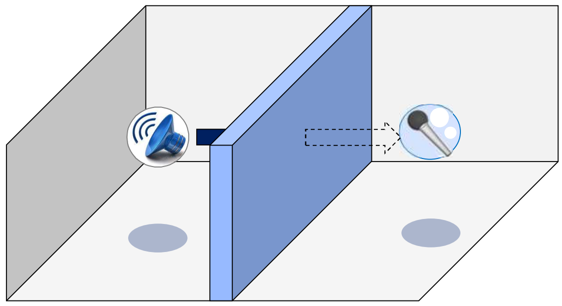
Sound occlusion



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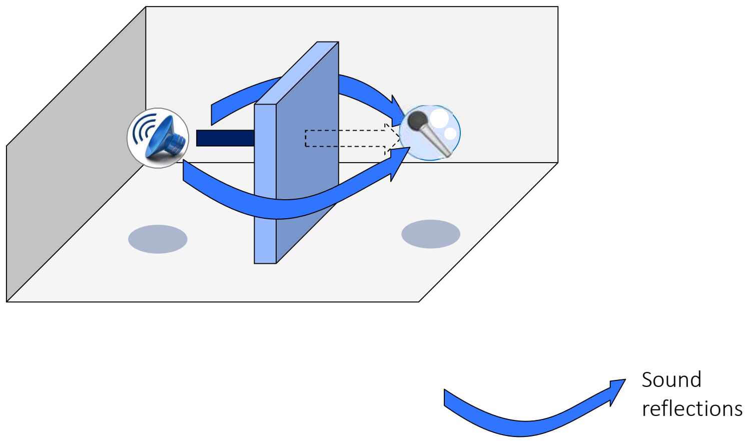
Sound obstruction



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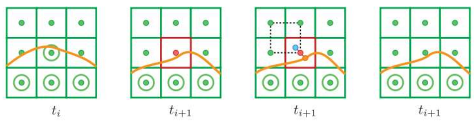
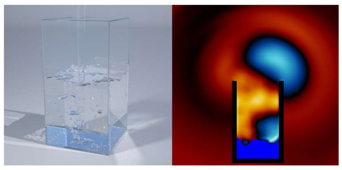
Sound Rendering: full computation of sound propagation in scene

- e.g., for collisions
- using physical material specification
- not (yet?) used in games
  - but active research topic





E.g. see: "Toward Wave-based Sound Synthesis for Computer Animation"
Jui-Hsien Wang, Ante Qu, Timothy R. Langlois, Doug L. James
SIGGRAPH 2018

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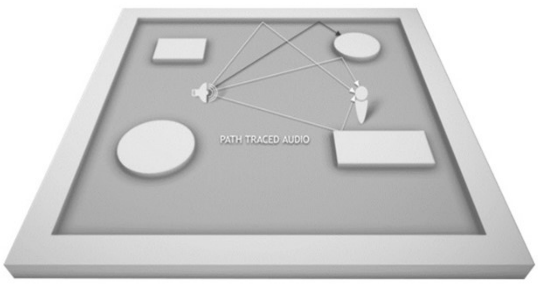
Sound reverb

- Solution 1: path tracing (expensive!)



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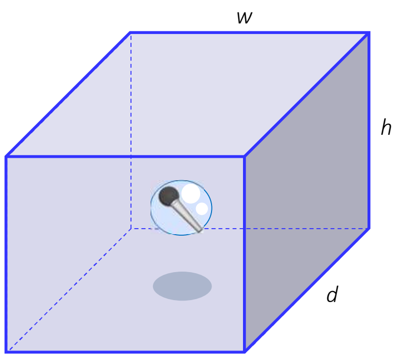
Sound Rerverb

- Solution 2: «shoe-box model»
  - An approximation that uses closed-form formulas



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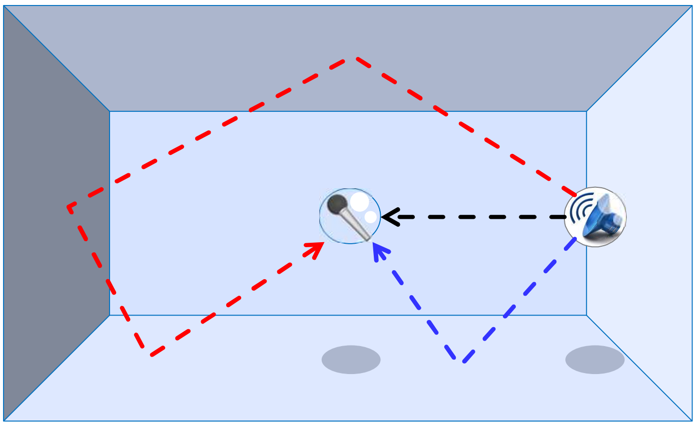
Shoe-box model for sound reverb



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What triggers sound fxs in a typical game-engine?

- fxs explicitly started from scripts
  - e.g. at collision response
  - e.g. accompanying all sorts of game logic
    - anything from *“doors opening”* to *“level completed”*
- fxs associated to scene Objects
  - constantly looped fx from a source, e.g. a radio
- fxs associated to interface elements
- fxs as Actions of the AI (see AI lecture)
  - see: AI for NPCs
- fxs associated to Animations (see animation lecture)
  - e.g. *footsteps* fxs during walk
  - e.g. *detach from ground* / *Land* fxs during jumps
  - e.g. *air-swishes* during sword swings
  - convenient to ease action/sound synchronization

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Authoring sound effects (task of the Sound Designer)

- Remember: as any asset, you can buy / get them from Libraries / Repositories
  - Common (so many needed fxs, so little time)
- Capture
  - Digital artist: “Foley”
  - Field capture (for ambient sounds → drones)
- Synthetize
  - by sound editing
  - (rarer)

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Voice Overs

- Two kinds:
  - Linear
    - e.g., cutscenes dialogs, narrations
  - Non-linear (e.g., driven by a state machine – see AI lecture)
    - e.g., dialogs trees
    - e.g., running commentary (of a football match)
- Technically, it’s nothing special. Just a sound fx.
- But, several practical challenges:
  - *Lots* of assets! (also implying file names, folders nightmare)
  - Localization often needed
  - Expensive production ($$$), late in the development
  - During early stages: better to use placeholders

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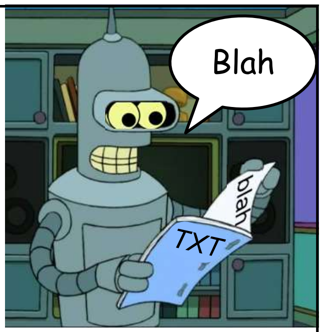
Speech Synthesis (or “text to speech”)



- A.I. frontier
- currently: still not good enough
  - not *believable* enough
    - human voice = we are all expert = difficult to trick us
    - audio “uncanny valley” ?
  - not *expressive* enough (emotions, characterizations)
  - i.e., virtual voice actors are not … good voice actors
- just a matter of time?
- when it will be here, it will
  - free games from most issues of voice-over assets
  - get us all the usual advantages of procedurality

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A summary of authoring sound assets

- Synthesized / simulated / procedural *fxs* :
  - baked
  - (rare)
- Captured *fxs* :
  - hardware: a good microphone!
  - by: "Foley artists"
  - very often: just bought / downloaded from repositories
- Voice :
  - hardware: a good microphone!
  - by voice actors
    - (sometimes, during motion capture sections)
  - speech synthesis? won't be used (for some time yet)

then, sound editing

- Composed (for music) :
  - musicians: frequent 3rd members of 3-man dev teams
  - recent improvements of tools (both HW and SW)
    - e.g. chorus with arbitrary lyrics now attainable
  - a few game composer gained substantial fame!

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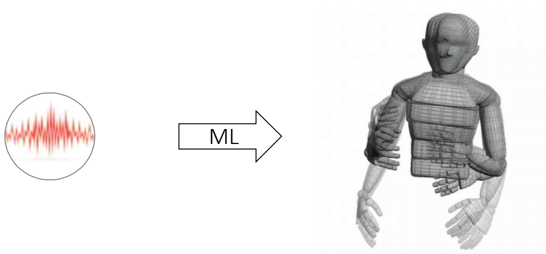
Research topic: from voiceovers to NPC animations

- With Machine Learning (data driven)



sound wave
of a voice-over

skeletal animation
for a virtual character believably gesticulating while speaking

"Style-Controllable Speech-Driven Gesture Synthesis Using Normalising Flows"
Simon Alexanderson et al, CGF (Eurographics 2020)

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