Listening to the Future:

Next Generation Sound Synthesis through Simulation

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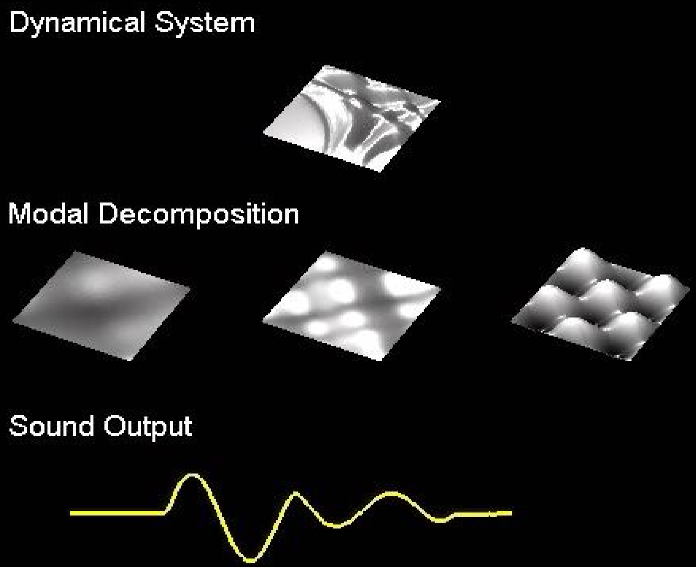
University of Edinburgh

Brussels, 11 May 2011

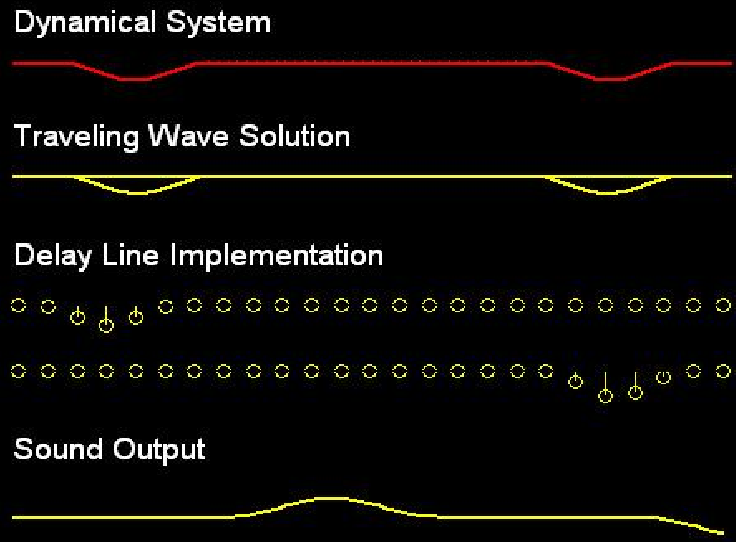
Physical Modeling Synthesis: State of the Art

- Physical modeling: currently most advanced synthetic audio rendering framework…
- Many techniques have emerged:

Modal Synthesis (IRCAM)

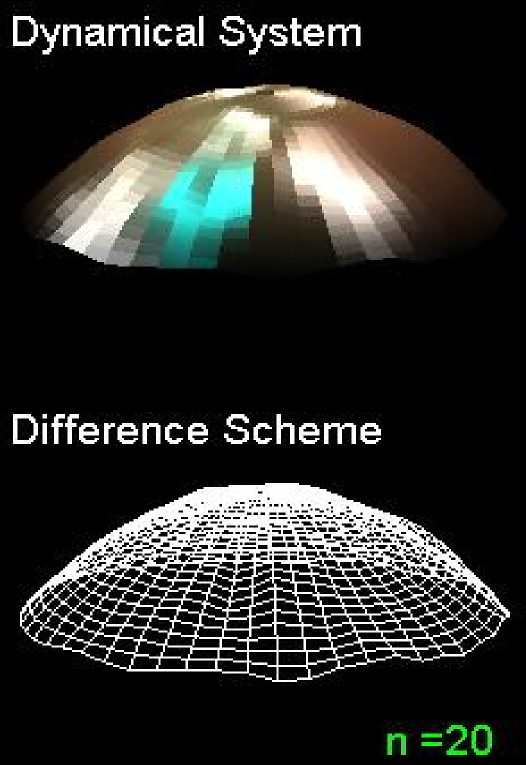


Digital Waveguides (Stanford)



- Efficient…but:
- Efficiency relies on strict (unphysical!) hypotheses, and especially linearity
- **Difficult/impossible to generalize to more realistic settings!**

Next Generation Sound Synthesis: Large Scale Time Domain Simulation



- Basic approach…time domain simulation (finite difference, finite volume, etc.)
- More general than other synthesis techniques… **can approach practically any virtual musical instrument**

- For comparison: percussion

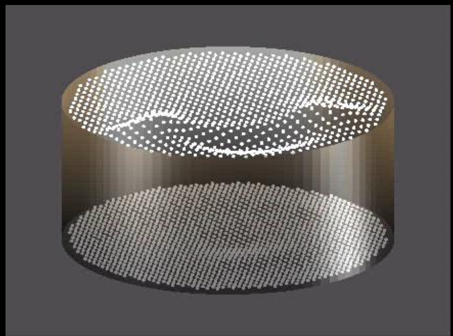
`Current Physical Modeling Technology:`

`Next Generation:`

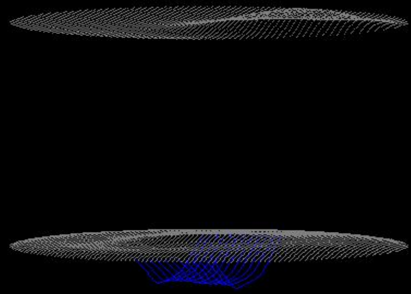
But: many algorithmic and computational challenges!

Building a Sound: The Snare Drum

- An interesting test case…
- Various levels of approximation:



Membranes only

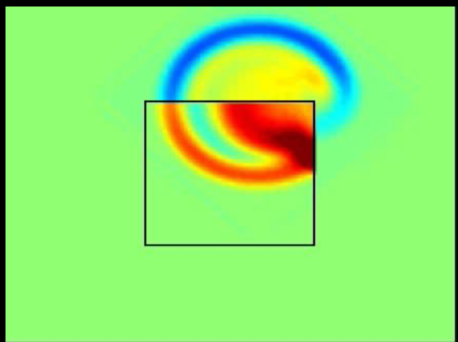


Membranes and snares

- Current technology:

Modal synthesis

Avanzini and Marogna, IEEE Transactions ASP 2011.
http://smc.dei.unipd.it/membranes.html#cs



Embedding in small 3D acoustic space

Embedding in large virtual room

Target Systems

- Span the full range of acoustic systems…
- Impossible to approach using other physical modeling techniques…

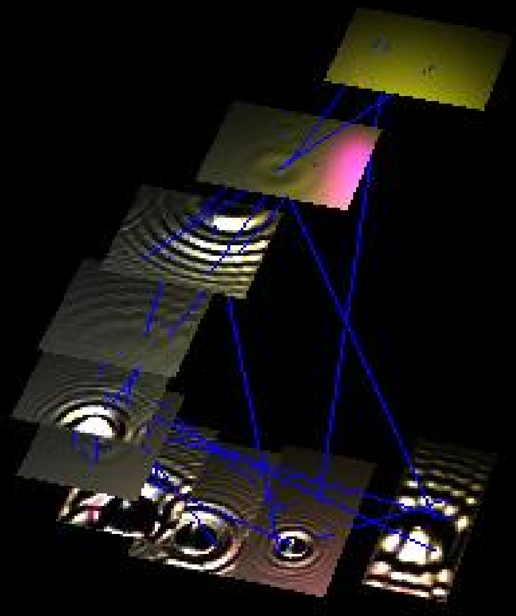
T1: Brass Instruments

T3: Nonlinear Plate and Shell Vibration

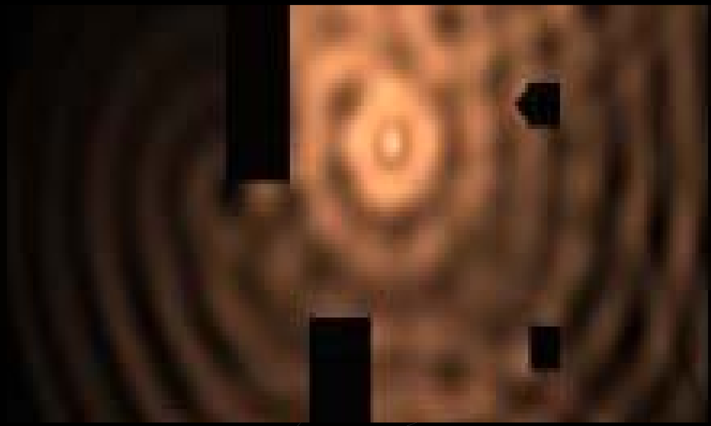
T2: Electromechanical Instruments

Target Systems: Continued

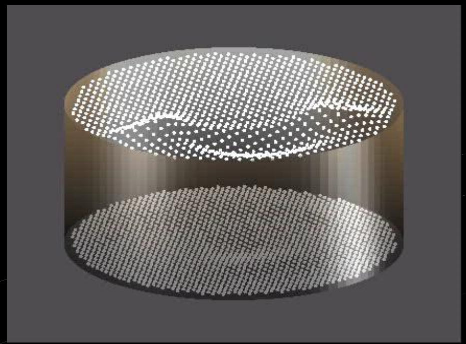
T4: Modular Synthesis Environments

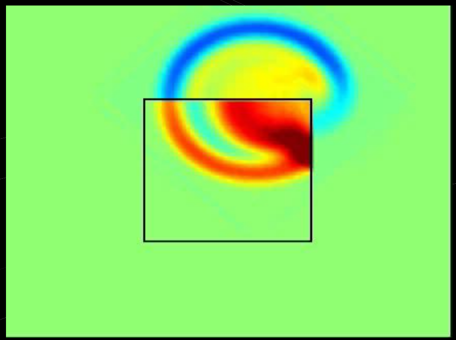


T5: Room Acoustics Modelling



T6: Embeddings and Spatialization

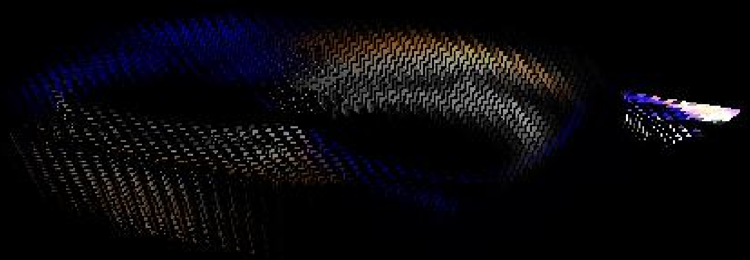




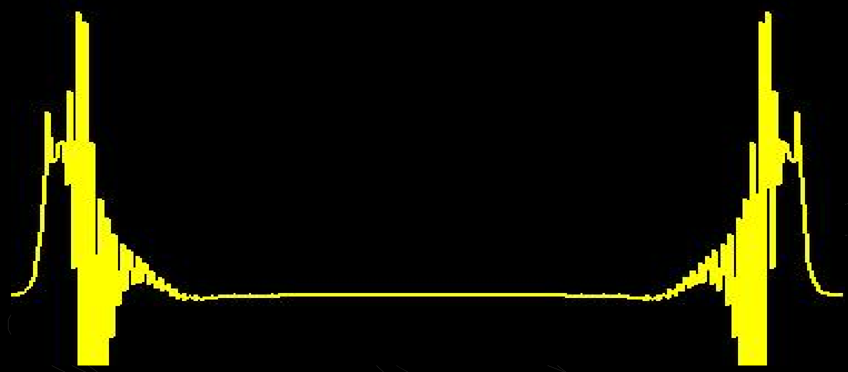
Algorithm Design

- Basic framework: Finite Difference Time Domain. Many issues…
- Need robust algorithm designs under highly nonlinear, modular conditions (stability)

Instability: membrane



Instability: shock wave propagation



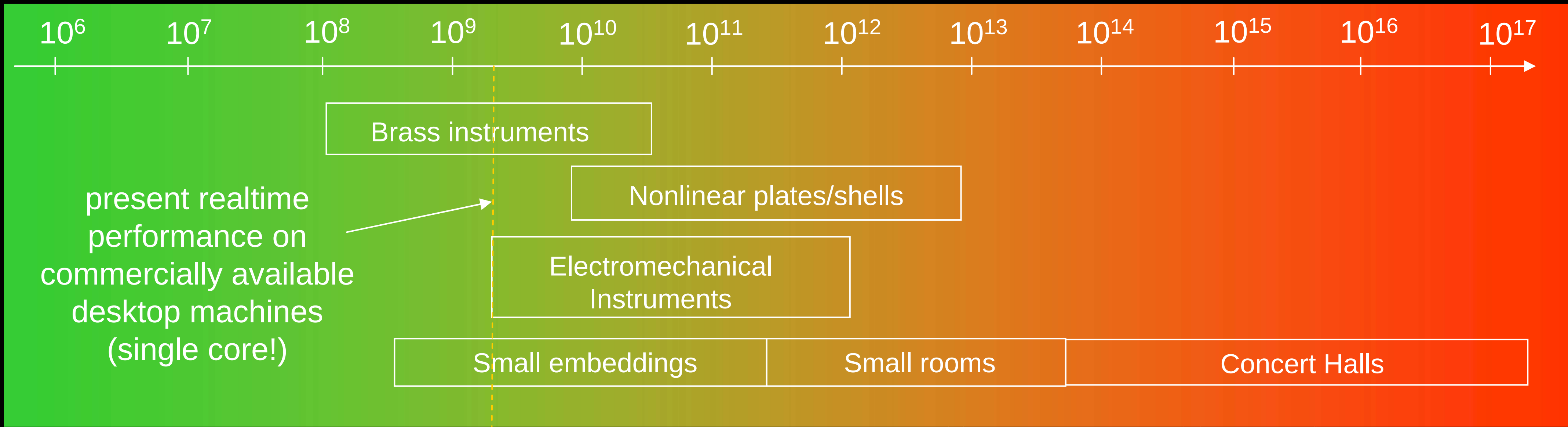
- Perceptual issues peculiar to audio:
  - frequency domain aliasing/spectral foldover
  - audio bandwidth limitation
  - interpolation (perceptually transparent)

→ algorithm designs must be specialized to audio!

Computational Costs and HPC

- Audio sample rates are high: 44 100 Hz, 48 000 Hz, 92 000 Hz…
- Flop rates/memory requirement scale as power of sample rate (2,3,4)…

arithmetic operations/second output, at 48 000 Hz:



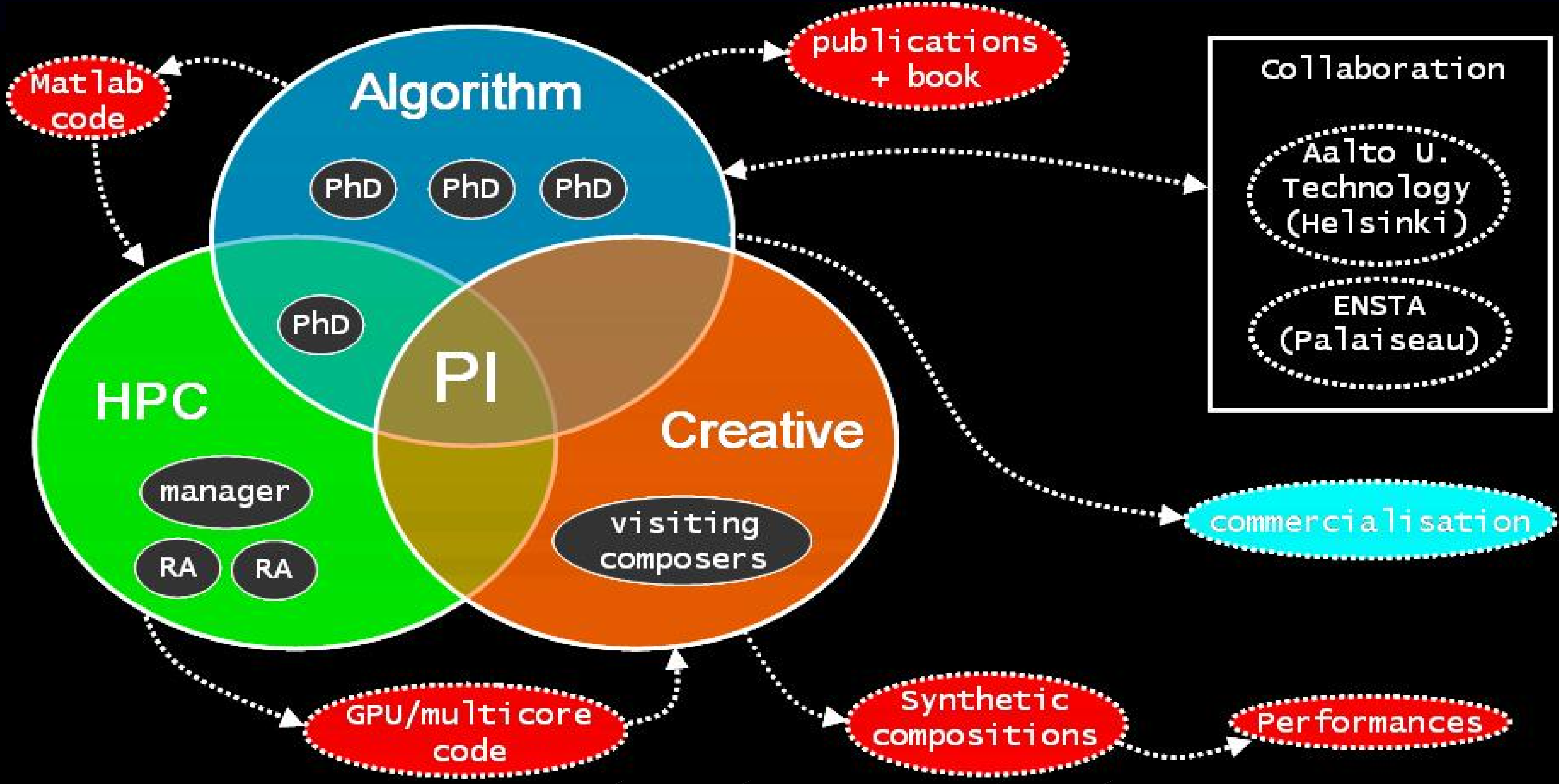
- Musical use/experimentation: reasonable compute time (no overnight jobs!)
- Solutions:
  - Multicore implementations (C)
  - GPGPUs (CUDA)
- New algorithmic issues: parallelizability, memory management, stability in finite precision

Creative Uses: Composition

- A new world of sound for musicians and composers---fully multichannel, synthetic music environments
- But---a learning curve! As for any mature instrument design…

Project Structure

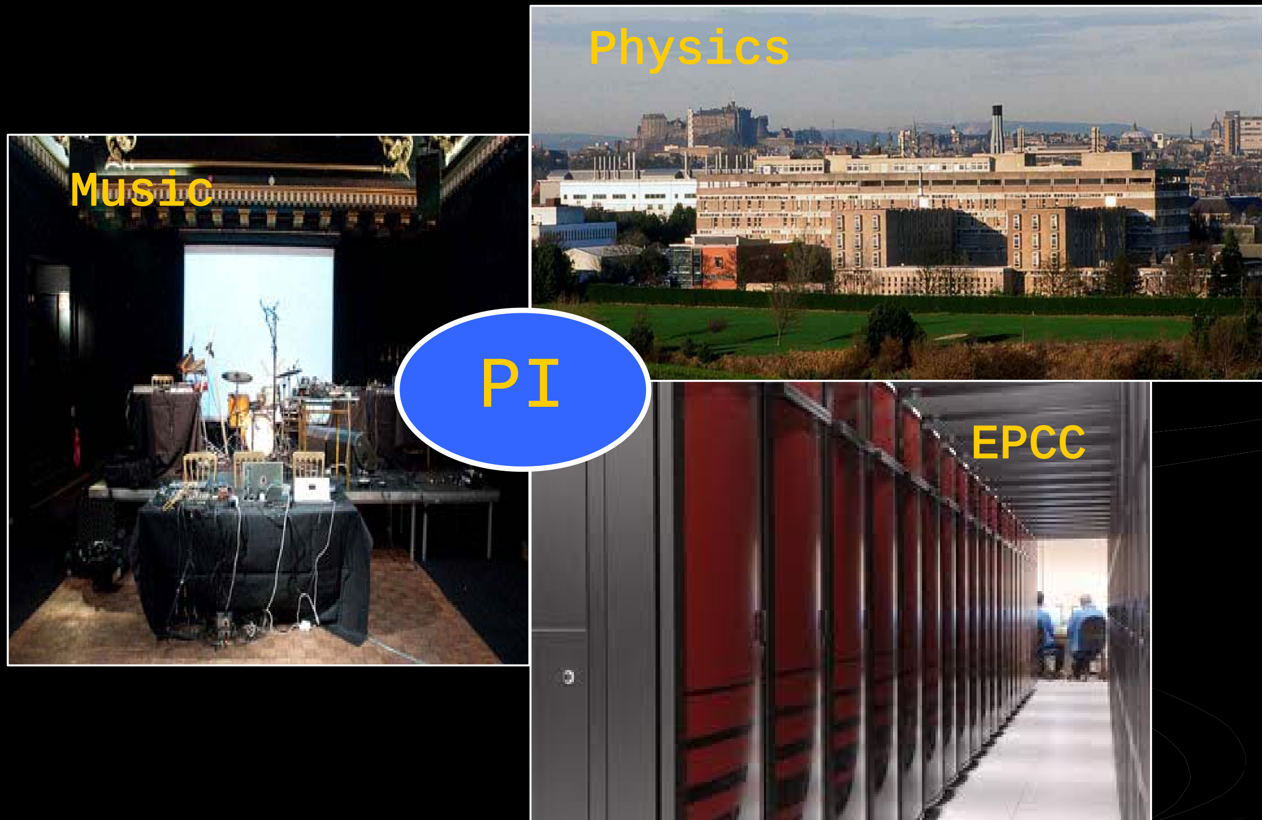
- A multidisciplinary project involving interaction/collaboration/feedback among three main groupings…



Research Environment: The University of Edinburgh

- Uniquely positioned for this project

- **Music:** electroacoustic composition, studio spaces, concert series…
- **Physics:** Acoustics group, laboratory spaces
- **EPCC:** Edinburgh Parallel Computing Centre



PI: Musical Acoustics appointment (Physics/Music) + links to EPCC

Why?

- **Why?**
  - Synthetic sound technology has changed little in 20 years--despite great increases in computational power! (Think of graphics.) Huge potential for improvement in sound quality!
  - But, need links with mainstream numerical simulation…
- **Why now?**
  - Only now is readily-available hardware able to tackle complex large-scale systems in a reasonable compute time…
- **Why me?**
  - Cross-disciplinary expertise: audio signal processing and computational mechanics…and many links to EU acoustics groupings
  - Personal links/direct work with musicians
  - Unique placement at Edinburgh at the crossroads of physics, music and HPC

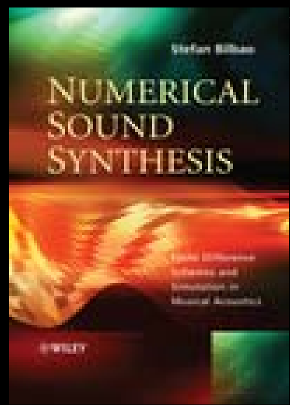
Thanks for your attention!

CV summary: Stefan Bilbao

- Current position: Senior Lecturer, Music, University of Edinburgh
- Background in physical sciences/engineering:
  - B.A., Physics, Harvard University, 1992
  - Ecole Normale Supérieure/Harvard University Exchange Fellowship 1992-1993
  - MSc./PhD, Electrical Engineering, Stanford University, 1996/2001
- Publications:
  - 18 journal publications (10 as sole author, 14 as main author)
  - 40 conference proceedings articles
  - 2 monographs:

Wave and Scattering Methods for Numerical Simulation

John Wiley and Sons, 2004



Numerical Sound Synthesis: Finite Difference Schemes and Simulation in Musical Acoustics

John Wiley and Sons, 2009

- **CV update (since application)**
  - **Varèse Guest Professor, Technical University of Berlin (DAAD), 2011/12**
  - **Edinburgh Physical Modeling Research (EPM): Funded commercial venture, University of Edinburgh, 2011.**

References

- General Digital Synthesis:
  - C. Roads. *The Computer Music Tutorial*, MIT Press, 1996.
- Modal Synthesis:
  - J.-M. Adrien. *The Missing Link: Modal Synthesis*. In Representations of Musical Signals, 269-297, G. DePoli et al., Eds., MIT Press, 1991.
- Digital Waveguide Synthesis:
  - J. O. Smith III. *Physical Modeling Using Digital Waveguides*, Computer Music Journal, 16(4):74-91, 1992.
- Source sound materials (other physical modeling methods):
  - Modal Synthesis:
    - http://support.ircam.fr/doc-modalys/spip/rubrique.php3?id_rubrique=3
    - http://smc.dei.unipd.it/membranes.html#cs
  - CORDIS-ANIMA:
    - http://www-acroe.imag.fr/mediatheque/sonotheque/sonotheque_en.html
  - Digital Waveguides:
    - https://ccrma.stanford.edu/~jos/pasp/Sound_Examples.html
- Source sound materials (next generation)
  - http://www2.ph.ed.ac.uk/~sbilbao/nsstop.html