Listening to the Future:

Next Generation Sound Synthesis through Simulation

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Physical Modeling Synthesis: State of the Art

- Physical modeling: currently most advanced synthetic audio rendering framework...
- Many techniques have emerged:
  - Modal Synthesis (IRCAM)
    - Dynamical System
    - Modal Decomposition
    - Sound Output
  - Digital Waveguides (Stanford)
    - Dynamical System
    - Traveling Wave Solution
    - Delay Line Implementation
    - Sound Output

- 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:

But: many algorithmic and computational challenges!
Building a Sound: The Snare Drum

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

- **Current technology:**
  - Modal synthesis
  - Avanzi and Marogna, IEEE Transactions ASP 2011. [http://smc.dei.unipd.it/membranes.html#cs](http://smc.dei.unipd.it/membranes.html#cs)
Target Systems

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

T1: Brass Instruments

T2: Electromechanical Instruments

T3: Nonlinear Plate and Shell Vibration
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)…

<table>
<thead>
<tr>
<th>Arithmetic operations/second output, at 48 000 Hz:</th>
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<tr>
<td>$10^6$</td>
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<td>---------------------------------------------</td>
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<tr>
<td>Present realtime performance on commercially available desktop machines (single core!)</td>
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<tr>
<td>Brass instruments</td>
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<td>Nonlinear plates/shells</td>
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<td>Electromechanical Instruments</td>
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<td>Small embeddings</td>
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- 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
References

- **General Digital Synthesis:**

- **Modal Synthesis:**

- **Digital Waveguide Synthesis:**

- **Source sound materials (other physical modeling methods):**
  - Modal Synthesis:
    - [http://smc.dei.unipd.it/membranes.html#cs](http://smc.dei.unipd.it/membranes.html#cs)
  - CORDIS-ANIMA:
  - Digital Waveguides:
    - [https://ccrma.stanford.edu/~jos/pasp/Sound_Examples.html](https://ccrma.stanford.edu/~jos/pasp/Sound_Examples.html)

- **Source sound materials (next generation)**
  - [http://www2.ph.ed.ac.uk/~sbilbao/nsstop.html](http://www2.ph.ed.ac.uk/~sbilbao/nsstop.html)