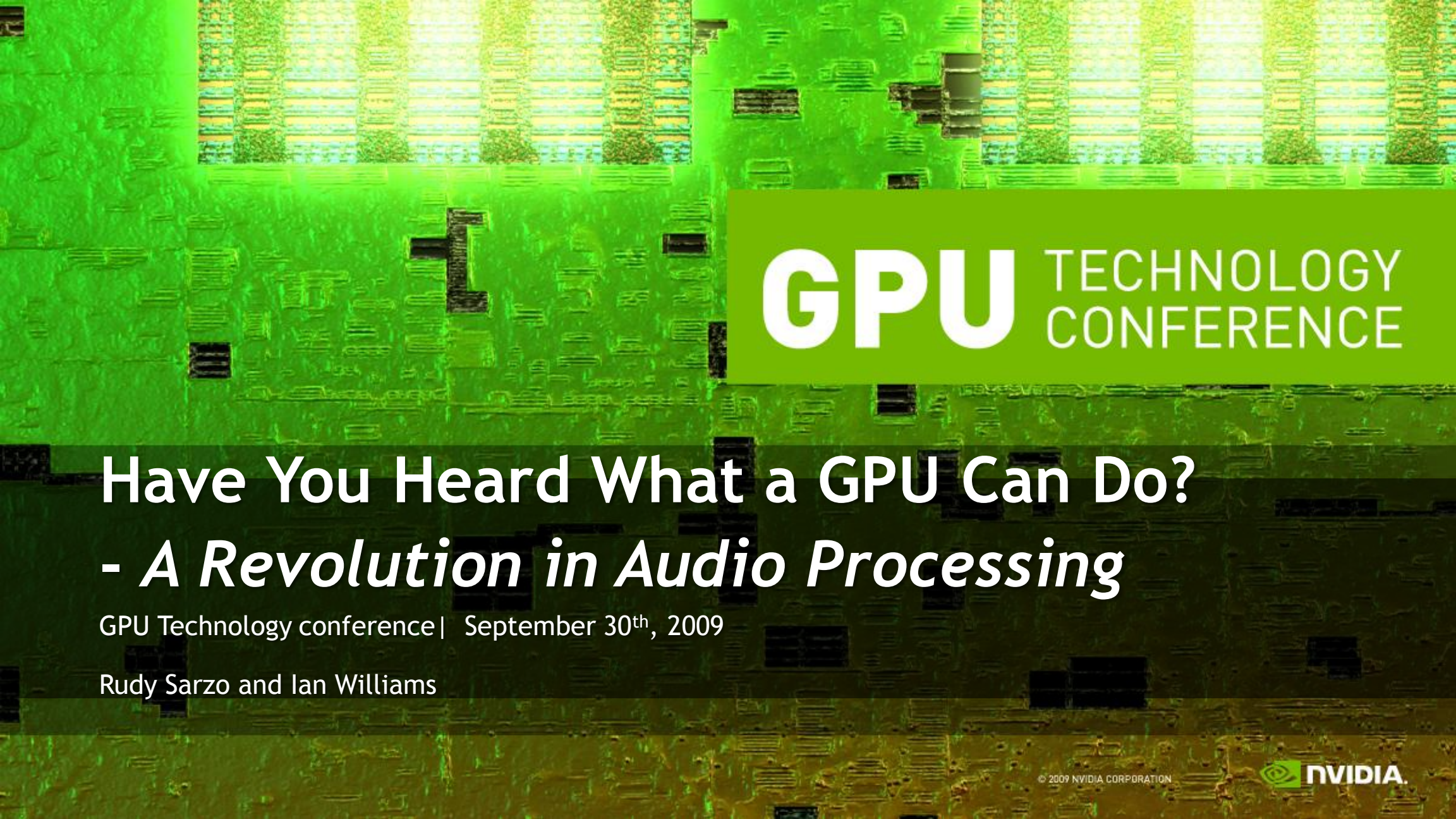


Have You Heard What a GPU Can Do?
- *A Revolution in Audio Processing*

GPU Technology conference | September 30th, 2009

Rudy Sarzo and Ian Williams

NVIDIA.

Have You Heard What a GPU Can Do? A Revolution in Audio Processing

- State of the Art for Digital Audio Processing - Ian
  - Background
  - Isn't Digital Audio a solved problem?
  - How the GPU can help?

- Integrating the GPU into the Professional Audio Workflow - Rudy
  - Professional Digital Audio tools and the workflow
  - Key problems with Digital Audio
  - How the GPU can revolutionize Digital Audio Processing

Digital Audio Processing is Ubiquitous

- Digital Audio is integrated into all areas of life
  - iPods, Media Players etc
  - Phones, Cellphones etc
  - Home Theater Systems, Digital TVs etc
  - PCs – Media Players, Audio Clean up software etc

- Audio processors cover spectrum of size and form factors
  - Dedicated ASICs, Engines, FPGAs, CPUs

- A wide range of Audio Editing Software
  - DAW software, Plugins etc.

Linear Convolution

- Current Digital Audio processing mostly based on Linear Convolution
  - Finite Impulse Response (FIR) filter $$y(j) = \sum_{i=0}^{N-1} x(j-i) \cdot h(i)$$
  - Samples of input waveform multiplied by samples of impulse response and summed
  - Stable – settles to zero after N+1 input samples
  - Doesn't require feedback – errors don't propagate
- Works well in a wide range of situations

Why use a GPU for Digital Audio?

Source: Hitch Hikers Guide to The Galaxy

What would Marvin say if he were a GPU:

"I have a Brain the size of a planet and you want me to convolve two buffers?"

Realism & Quality Drive Up Computational Complexity

- Linear assumptions have key limitations:
  - Can frequently sound “dry” & “unnatural”
- Some desirable characteristics occur because of non-linearities
  - e.g. harmonic distortion
- Many effects are also time variant, e.g. flanging, Phasing etc.
  - modeling these significantly increase computational complexity
- Multi-channel
  - Allows greater control over sound placement & mix => better experience

Co-Processing for Digital Audio

- An Orchestra needs a great conductor
- However….the conductor shouldn't play each instrument!
- Historically professional Digital Audio Editing has required dedicated Audio DSPs
- The GPU is a great Audio DSP
  - and its already in the system! ☺

Image courtesy of Digidesign

Emulating Non-Linear Characteristics in Digital Audio

- Impulse Response (IR) Switching
  - IR measured for different amplitudes of signal
  - IR selected based on input amplitude

- Focusrite – Liquid Technology using *"Dynamic Convolution"*

  Focusrite LIQUID 4 Pre Preamp

Focusrite LIQUID 4 Pre

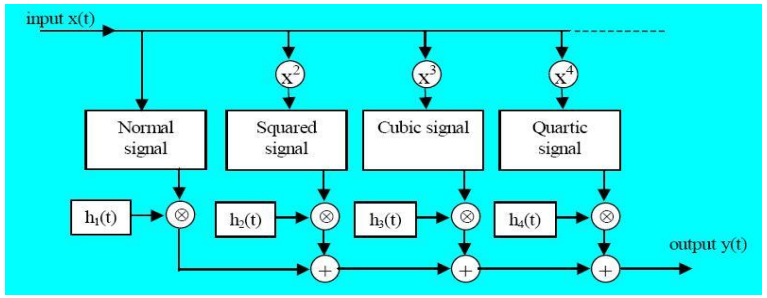
Emulating Non-Linear Characteristics in Digital Audio (cont.)

- Volterra Series
  - Volterra Series similar to Taylor Series
  - Taylors series output depends strictly on the input at a particular time
  - Volterra series output depends on the input to the system at all other times

Emulating Non-Linear Characteristics in Digital Audio (cont.)

- Volterra Series
  - Volterra Series similar to Taylor Series
  - Taylors series output depends strictly on the input at a particular time
  - Volterra series output depends on the input to the system at all other times
- Diagonal Volterra Kernels
  - Convolve 1st (linear) order IR, 2nd order IR, 3rd order IR, etc separately then sum the result
  - Each order IR is convolved with the input signal raised to the appropriate power:

$$y(n) = \sum_{i=0}^{M-1} h_1(i) \cdot x(n-i) + \sum_{i=0}^{M-1} h_2(i) \cdot x^2(n-i) + \sum_{i=0}^{M-1} h_3(i) \cdot x^3(n-i) + \ldots..$$



Source: "Realtime auralization employing a not-linear, not-time-invariant Convolver", Angelo Farina 1, Adriano Farina 2, AES 2007

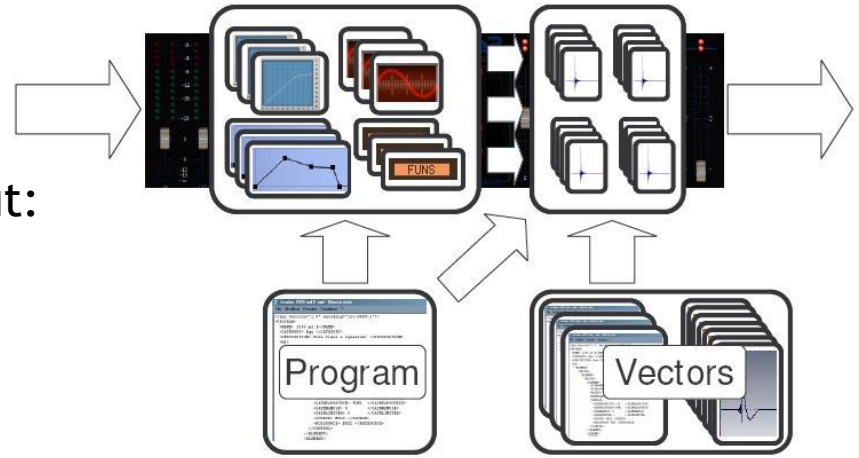
State of the Art Digital Audio Processing

ACUSTICA Audio – Nebula 3

- VST based plug-in implementing Vectorial Volterra Kernel Technology
- Multiple simultaneous, non-Linear, time varying, level dependent effects

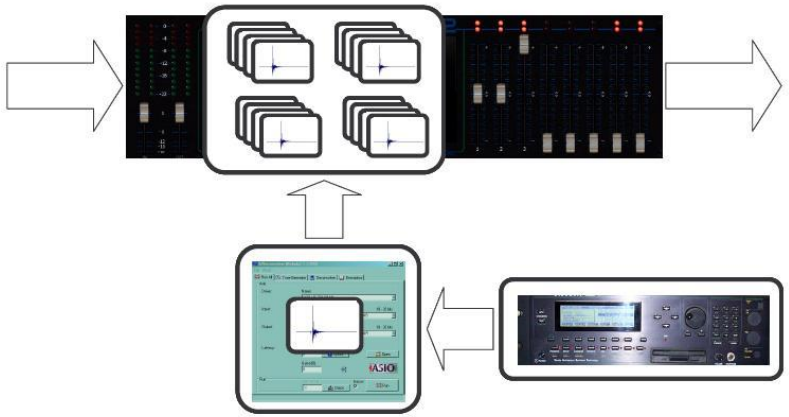
ACUSTICA Audio - Nebula 3

- Kernel Engine
  - Processes large number of kernels simultaneously
  - Controlled by the Vectorial Engine
- Vectorial Engine
  - Operates at defined rate (PROG RATE)
  - Many IR samples continually swapped in and out:
    - Multiple IRs per effect
    - Multiple simultaneous effects
    - Time dependent IRs
    - Settings within effects
- Accurate Modeling of Complex Sophisticated Effects
  - Dynamic harmonic distortion – valve preamps & compressors



ACUSTICA Audio – Nebula Sampler

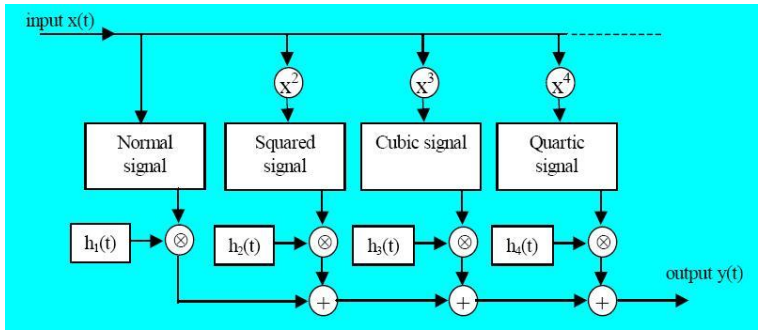
- Comes with Nebula 3
- Automates measurement of IRs
  - Including level and time and dependent Irs
- Easy to create new libraries of complex sophisticated effects



http://www.alessandroboschi.eu/html/en/alexb.htm

How Nebula 3 Uses NVIDIA CUDA

- Vectorial Engine currently operates on the CPU
- Kernel Engine implemented entirely on the GPU
  - CUDA Streams
  - Efficient algorithm leaves partial results for each harmonic on the GPU, only final results transferred off GPU:



  - Uses CU FFT library as well as hand tuned Vasily Volkov FFT algorithms

Rudy Sarzo

Digital Audio – "The Process"

Shrinking the recording studio into a computer

Studio Tour

Source: www.vai.com

Sony Acid Pro 7

How does a Professional Musician use Digital Audio?

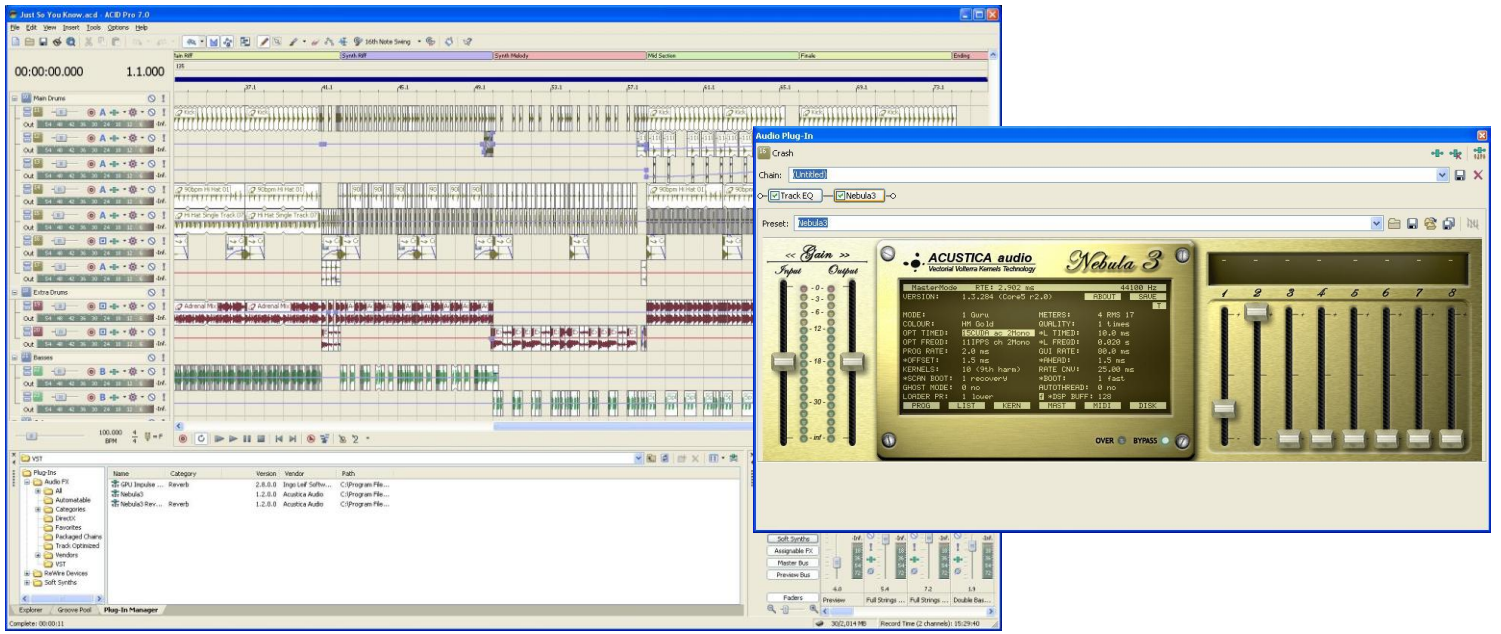
- Recording
  - Highest quality very important - bit depth, sample rate etc
  - Balancing what's practical for editing
  - No Clicks!!
- Editing
  - Retaining high quality is still crucial
  - Need to be able to work with many effects
  - Evaluate alternative mixes - stereo->mono, low bit rate mp3
- Playback
  - Create multiple delivery formats/mixes – MP3, AC3, 2.0, 5.1 etc.

Key Problems in Digital Audio

- Overloading / Insufficient headroom during recording
  - Clicks (relying to heavily on CPU - cycle overload)
- Poor quality effects/algorithms/HW
  - Just sound bad
  - Captures clicks (again relying to heavily on CPU - cycle overload)
- Hard limits on the number of simultaneous effects
  - Not enough CPU cycles for processing
  - Mixing takes longer
  - Workflow changes depending on platform (laptop, deskside DAW)
- .....

The Benefits the GPU brings to Digital Audio

Demonstration of CUDA Processing for Audio



Sony Acid Pro + Nebula3 VST Plug-in built on CUDA Technology

NVIDIA.

A Revolution in Audio Processing

- Digital Audio is here to stay
- The GPU is the perfect co-processor
  - And its already in the system
- The CUDA Architecture is the catalyst

- Fermi Architecture introduces new key features to benefit audio

Thanks!

- Questions?