Partitioned Convolution
For Real-Time Audio Effect Processing

Eric Battenberg, David Wessel, Juan Colmenares

ericb@eecs.berkeley.edu, wessel@cnmat.berkeley.edu, juancol@eecs.berkeley.edu

The Application

- ***First real-time app in the Par Lab.***
- Partitioned Convolution – an efficient way to do low-latency filtering with a long impulse response.
- Used in convolution reverb for environment simulation, creative effect processing, and electronic instrument creation.

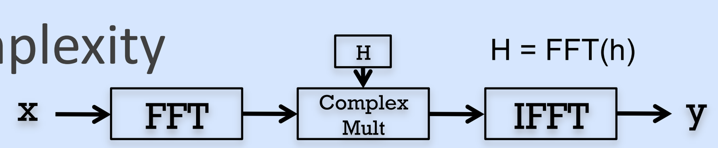
Convolution

- Convolution is a way to do linear filtering using an FIR (finite impulse response).
- Filter length, L, can be > 100,000 (3 sec)
- Direct Convolution:
  - O(L) complexity
  - Zero delay

$$y[n] = \sum_k h[k]x[n-k]$$

y – output, x –input, h - filter

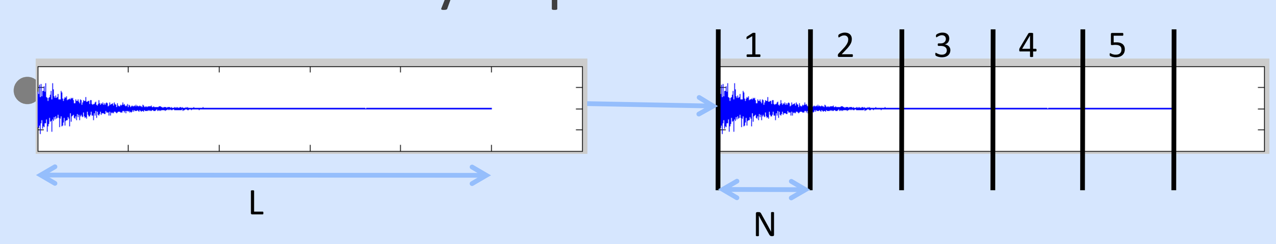
- Block FFT Convolution:
  - O(log(L)) complexity
  - L delay



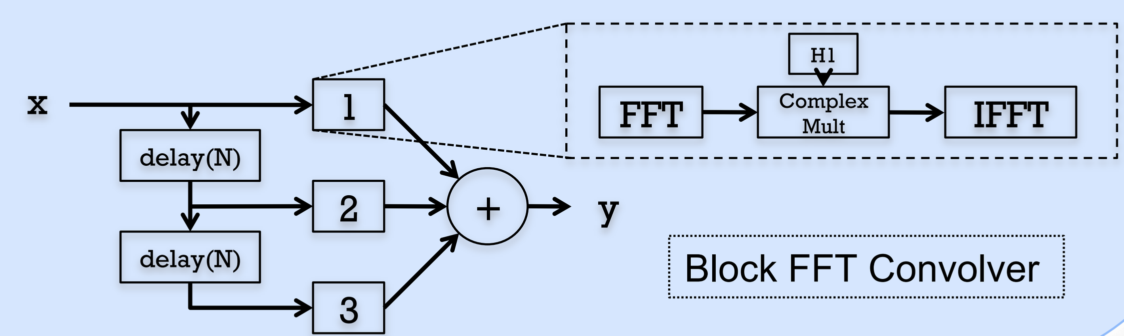
- We would like the delay to be less than 512 samples (10ms)

Uniform Partitioning

- To trade off between complexity and latency we can split the filter into smaller delayed parallel filters.

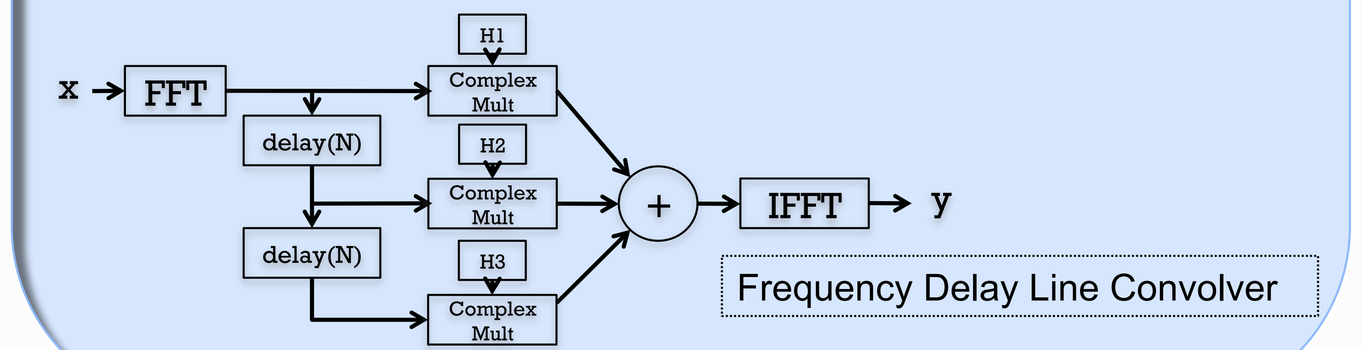


- This reduces latency to N, but increases the number of FFTs we must compute.



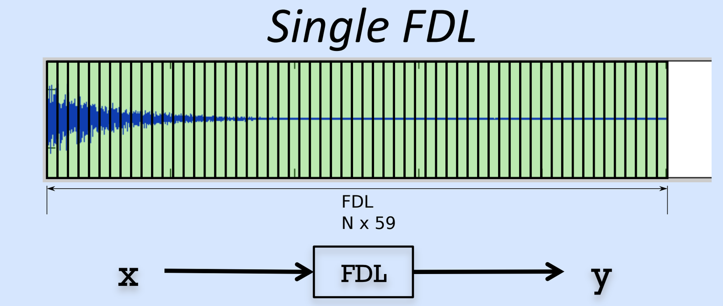
Frequency Delay Line (FDL)

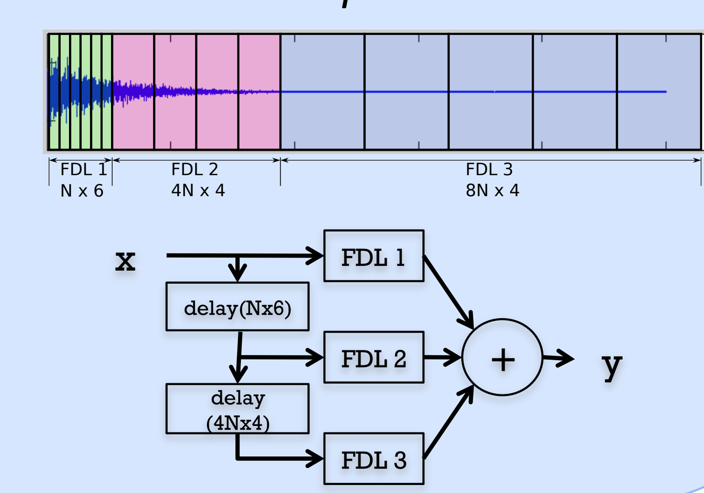
- With Uniform Partitioning, we can exploit linearity of FFT's by moving them outside of the parallel delay line.
- In this "FDL", we only have to compute one FFT/IFFT per iteration.



Multiple FDL's

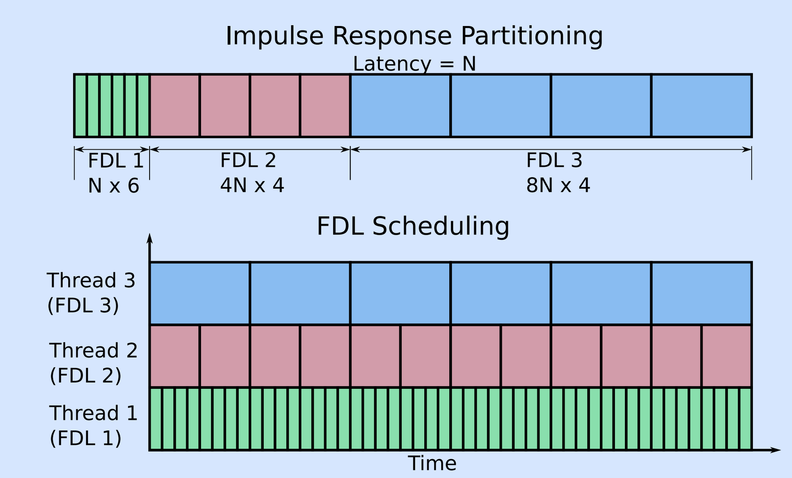
- With a long filter and a small block size, we may end up with hundreds of partitions in an FDL.
- To cover more samples per partition, we can run larger FDL's in parallel.
- This presents us with a tuning problem: *What is the best set of FDL's for a particular filter length and latency?*





Auto-Tuning for Real-Time

- We are *not* only trying to maximize throughput.
- We want to improve the validity of real-time guarantees.
- For now, we estimate a Worst-Case Execution Time (WCET) then combine FDL's that are most likely to meet their deadlines (vertical lines in scheduling diagram).
- We will progress to more robust scheduling as a next step.



Top-An example multi-FDL partitioning. Bottom-How each FDL-thread is scheduled in time.