Accelerating Bit Error Rate Simulation in MATLAB using Graphics Processors

High-Performance Embedded Computing Workshop (HPEC 2011)
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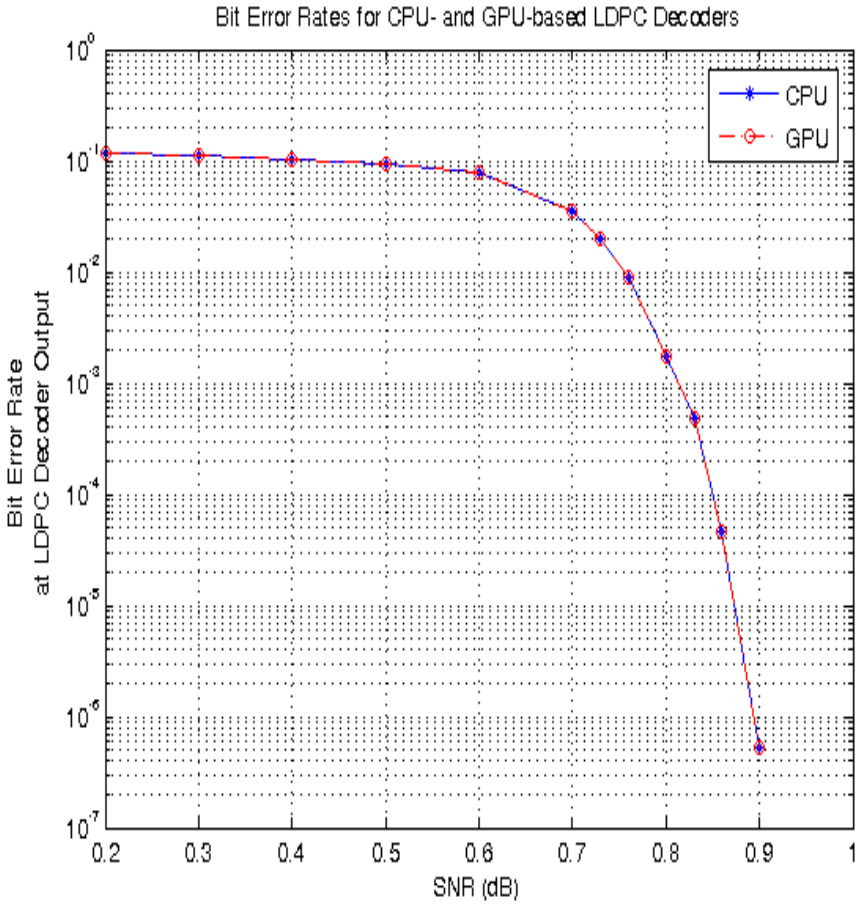
Outline

- Application Area
- MATLAB Tools
- DVB-S.2 Subset benchmark
- DVB-S Subset benchmark
- Conclusions

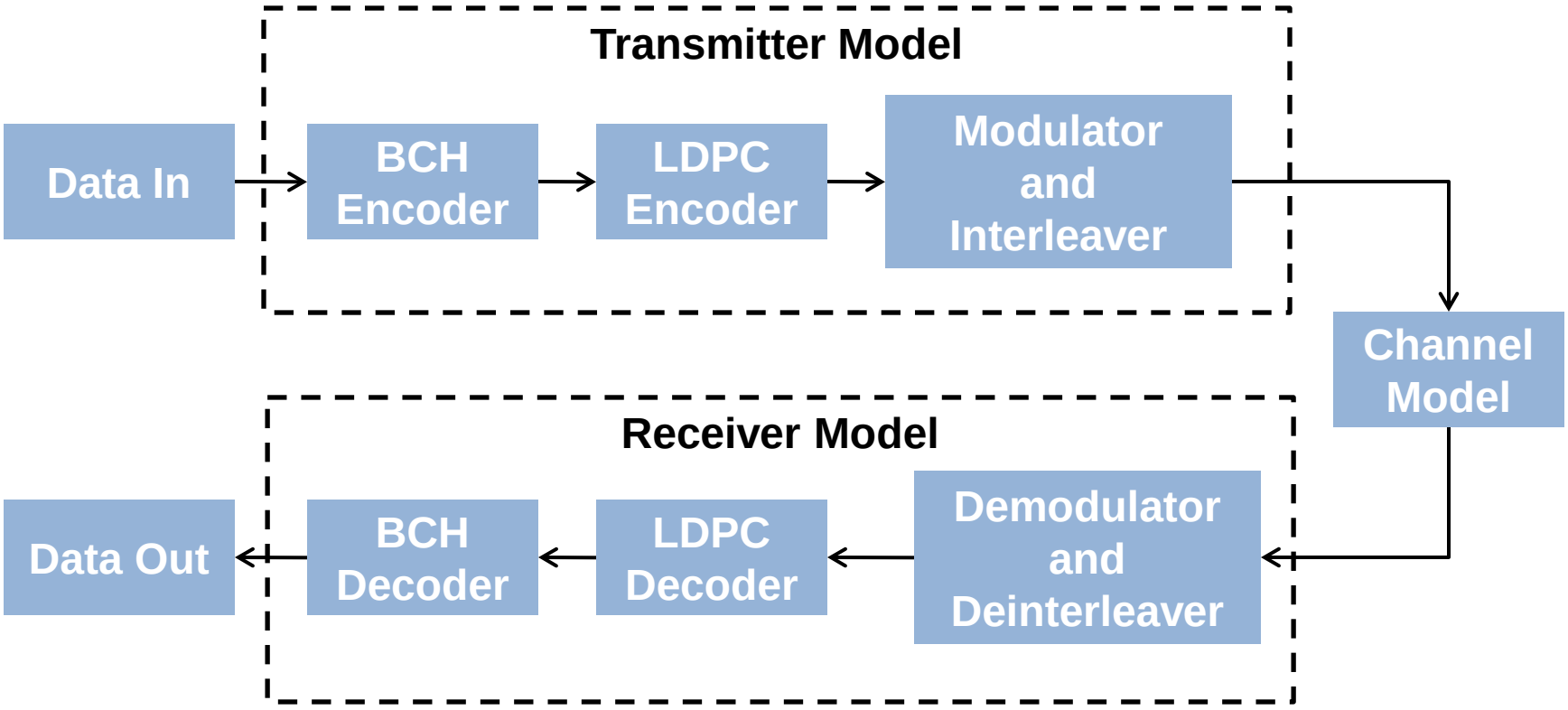
Bit Error Rate Simulation

- Begin with a model of a communications system
- Vary the signal-to-noise ratio
- Calculate bit error rate through Monte Carlo simulation
- Obtain a curve like that at the right
- Expensive (millions of trials, days of simulation)



Example System Model

Digital Video Broadcast Standard, Second Generation (DVB-S.2)



LDPC = Low-Density Parity Check

Simulation Goal: Verify transmitter and receiver achieve a given bit error rate in the presence of noise introduced by the channel model

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System Objects

System objects allow design of dynamic systems in MATLAB

Represent dynamic systems

- Algorithms with input values and states that change over time

Optimized for iterative execution

- One-time checking of parameter values, input arguments
- Data streaming between objects

Many algorithms implemented in C++ for speed

Support for automatic C code generation

System Object Receiver Model

```
%***Receiver Object Creation ***
hDemod = comm.PSKDemodulator(demodulatorArgs{:});
hDeintrlv = comm.BlockDeinterleaver(dvb.InterleaveOrder);
hDec = comm.LDPCDecoder(decoderArgs{:});
```

System Object Receiver Model

```
%***Receiver Object Creation ***
hDemod = comm.PSKDemodulator(demodulatorArgs{:});
hDeintrlv = comm.BlockDei[illegible]aver(dvb.InterleaveOrder);
hDec = [illegible]
```

```
{'ModulationOrder', 2^dvb.BitsPerSymbol, ...
 'BitOutput', true, ...
 'PhaseOffset', dvb.PhaseOffset, ...
 'SymbolMapping', 'Custom', ...
 'CustomSymbolMapping', dvb.SymbolMapping, ...
 'DecisionMethod', 'Approximate log-likelihood ratio', ...
 'Variance', dvb.NoiseVar}
```

System Object Receiver Model

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%***Receiver Object Creation ***
hDemod = comm.PSKDemodulator(demodulatorArgs{:});
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```
%***Receiver Model Execution***%
demodOut    = step(hDemod, chanOut);
dexlvrOut   = step(hDeintrlv, demodOut);
ldpcdecOut  = step(hDec, dexlvrOut);
```

Graphics Processing Unit (GPU) Acceleration in MATLAB

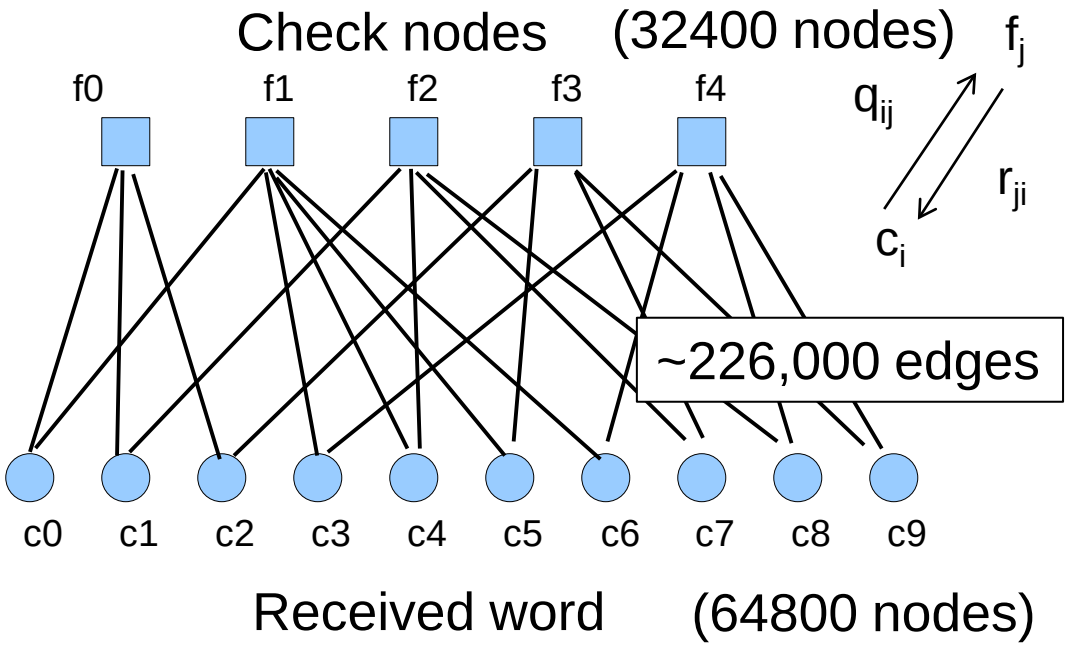
Level of control	*Required effort*	*Parallel options*
Minimal	**None**	**Use GPU arrays with MATLAB built-in functions**
Some	**Straightforward**	**Execute custom functions on elements of GPU arrays**
Extensive	**Involved**	**Create kernels from existing CUDA code and PTX files**

Requirements

- **Parallel Computing Toolbox**
- **NVIDIA GPU with Compute Capability 1.3 or greater**

LDPC Decoder

LDPC Decoder was implemented using custom CUDA kernels in MATLAB release R2011a



Iteratively determine message bits that best satisfy system constraints

LDPC Decoder Algorithm

```
for ii=1:maxIterations,
        Update all r messages (in parallel)
        Update all q messages (in parallel)
end
form hard/soft decision (in parallel)
```

GPU-Accelerated Receiver Model

```
%***Receiver Object Creation ***
hDemod = comm.PSKDemodulator(demodulatorArgs{:});
hDeintrlv = comm.BlockDeinterleaver(dvb.InterleaveOrder);
hDec = comm.gpu.LDPCDecoder(decoderArgs{:});

  %***Receiver Model Execution***%
  demodOut    = step(hDemod, chanOut);
  dexlvrOut   = step(hDeintrlv, demodOut);
  ldpcdecOut  = step(hDec, dexlvrOut);
```

- Minimal code changes to use GPU System Object
- GPU System object is 20x faster than original System object
- Overall system simulation is 5x faster

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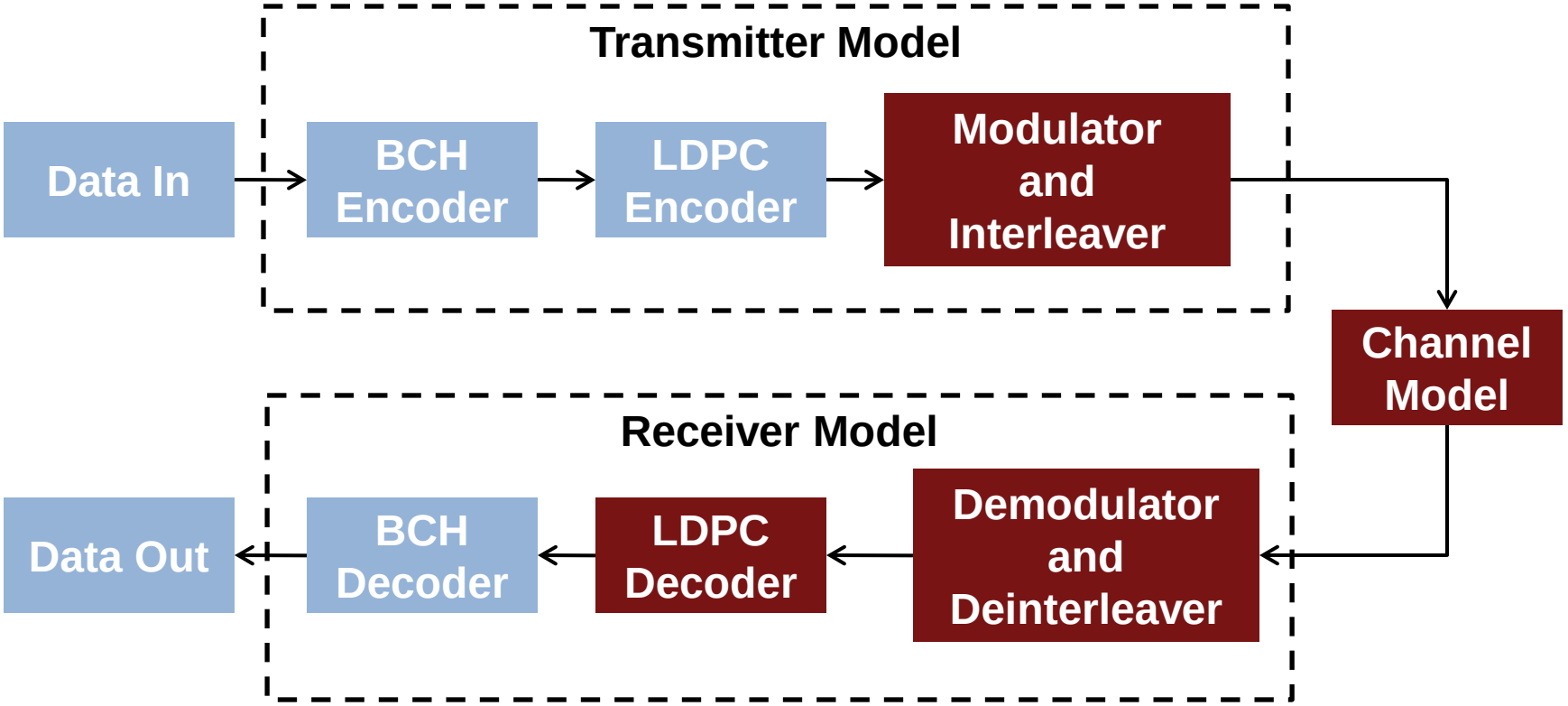
DVB-S.2 Subset Benchmark

Digital Video Broadcast Standard, Second Generation (DVB-S.2)



Subset benchmark (can execute entirely on GPU)
New objects implemented using MATLAB for faster development

Using GPU System objects

- GPU System objects are *drop-in replacements* for standard System objects
  - Normal MATLAB arrays in ➔ normal MATLAB arrays out
  - Requires two data transfers

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Using GPU System objects

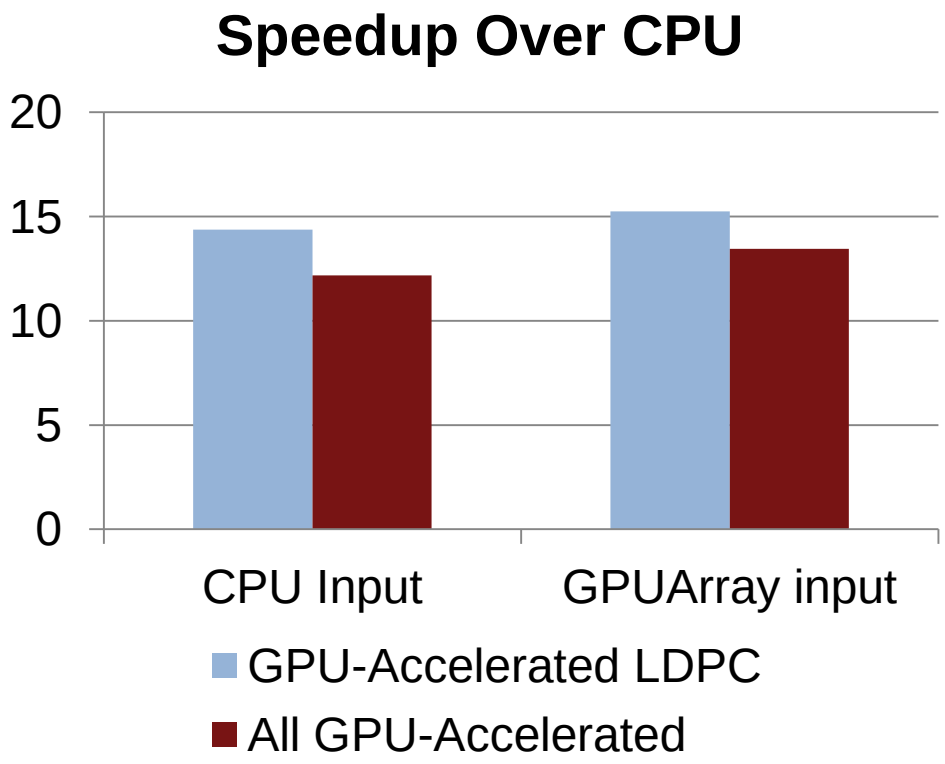
- GPU System objects are *drop-in replacements* for standard System objects
  - Normal MATLAB arrays in ➔ normal MATLAB arrays out
  - Requires two data transfers
- GPU System objects also accept GPUArrays as inputs
  - In this case the output is also a GPU Array
  - Avoids data transfer overhead

```
%***Receiver Object Creation ***
hDemod = comm.gpu.PSKDemodulator(demodulatorArgs{:});
hDeintrlv = comm.gpu.BlockDeinterleaver(dvb.InterleaveOrder);
hDec = comm.gpu.LDPCDecoder(decoderArgs{:});

  %***Receiver Model Execution***%
  demodOut    = step(hDemod, gpuArray(chanOut));
  dexlvrOut   = step(hDeintrlv, demodOut);
  ldpcdecOut  = gather(step(hDec, dexlvrOut));
```

DVB-S.2 Subset Benchmarks Using GPUArray

- **Baseline: speed of subset with all objects on the CPU**
- **Using GPUArray objects as inputs accelerates both versions of the benchmark**
- **Using the GPU-accelerated LDPC provides a large performance boost**
- **Adding GPU-accelerated versions of other objects slows down the simulation**

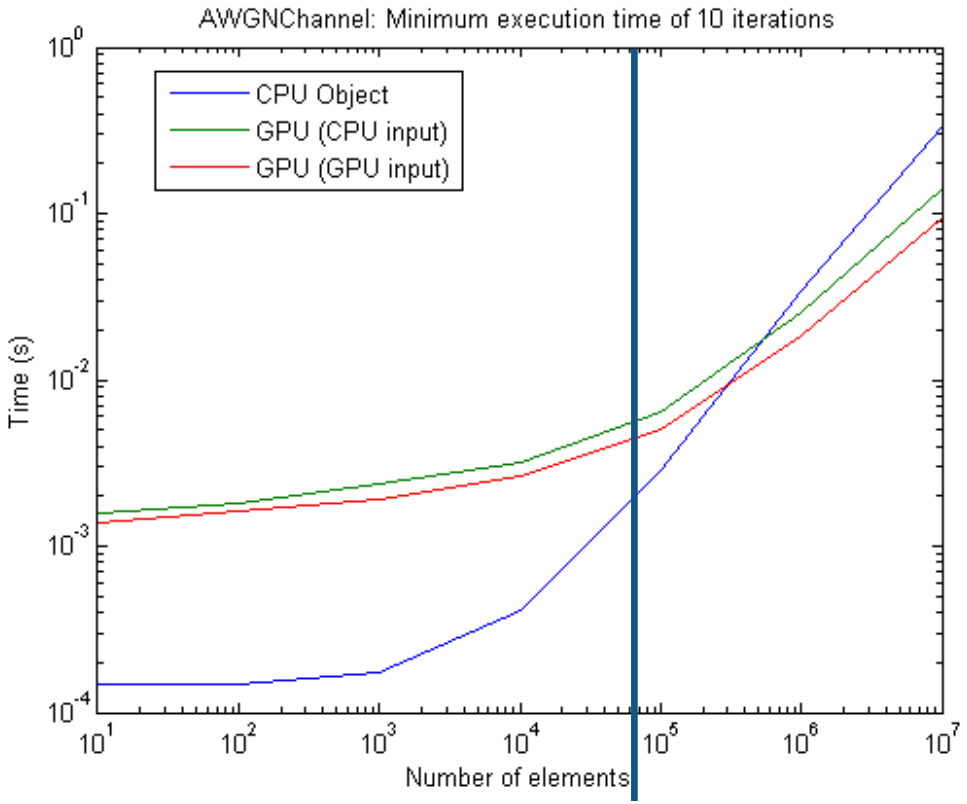


Benchmark Machine Specs

CPU: 2.5 GHz Intel Core 2 Quad
GPU: NVIDIA Tesla C1060
Windows 7
MATLAB R2011b

Performance vs. Input Size for GPU System Objects

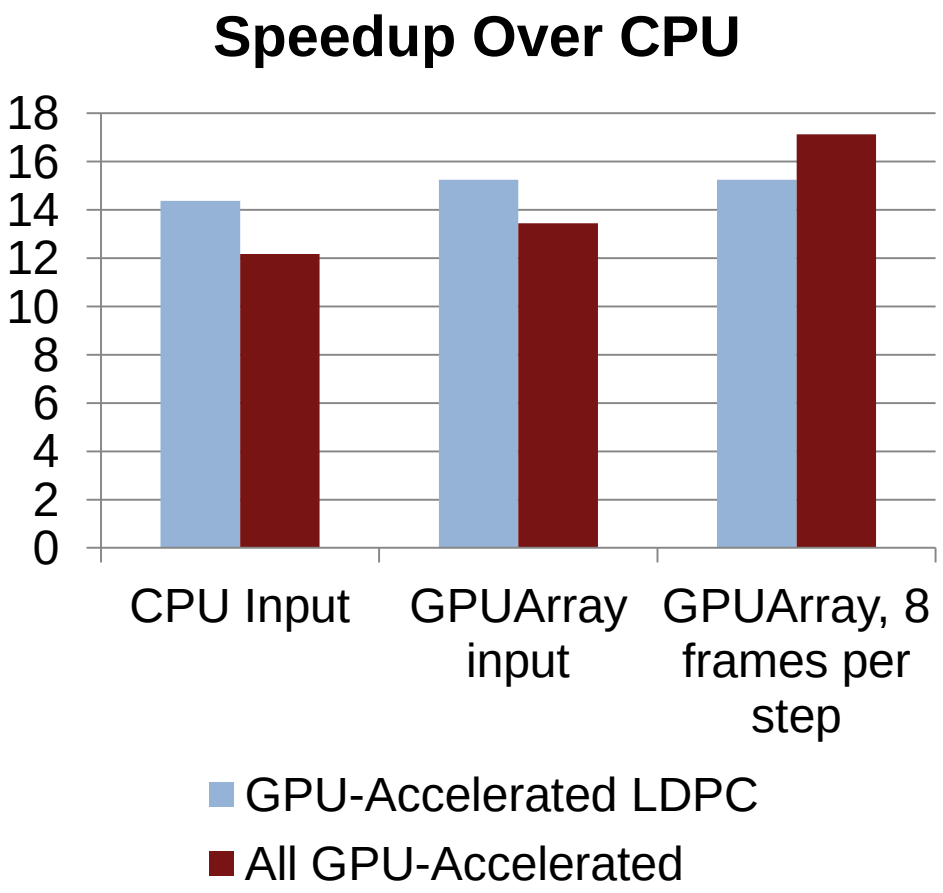
- **Computational density is important for obtaining good GPU performance**
- **Many GPU System objects are slower for small data sizes**
- **In R2011b, crossover point is generally around 10^5**
- **Frame size is 64800 elements**



System Frame Size

DVB-S.2 Subset Multi-Frame Benchmarks

- **Process 8 frames of data on the GPU simultaneously to get better performance**
- **LDPC performance begins to saturate, but other objects become faster**



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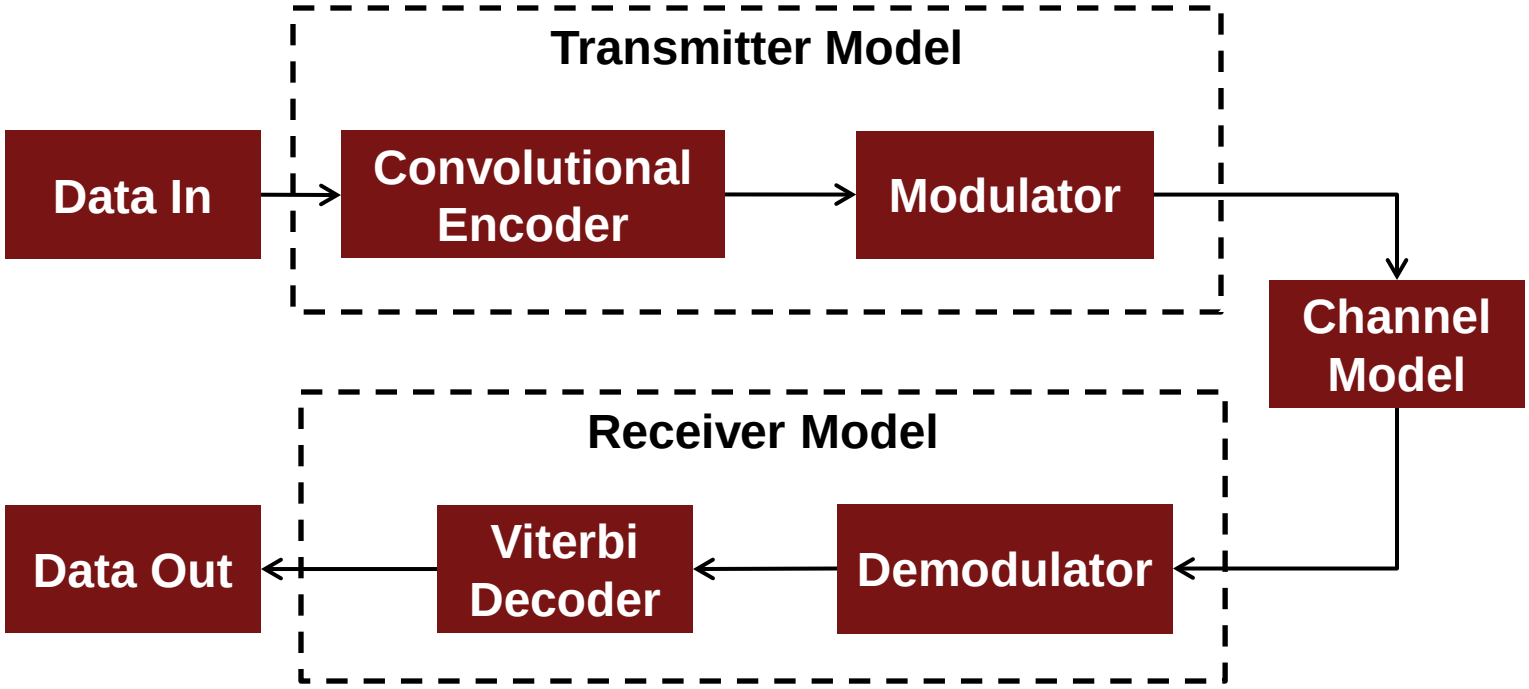
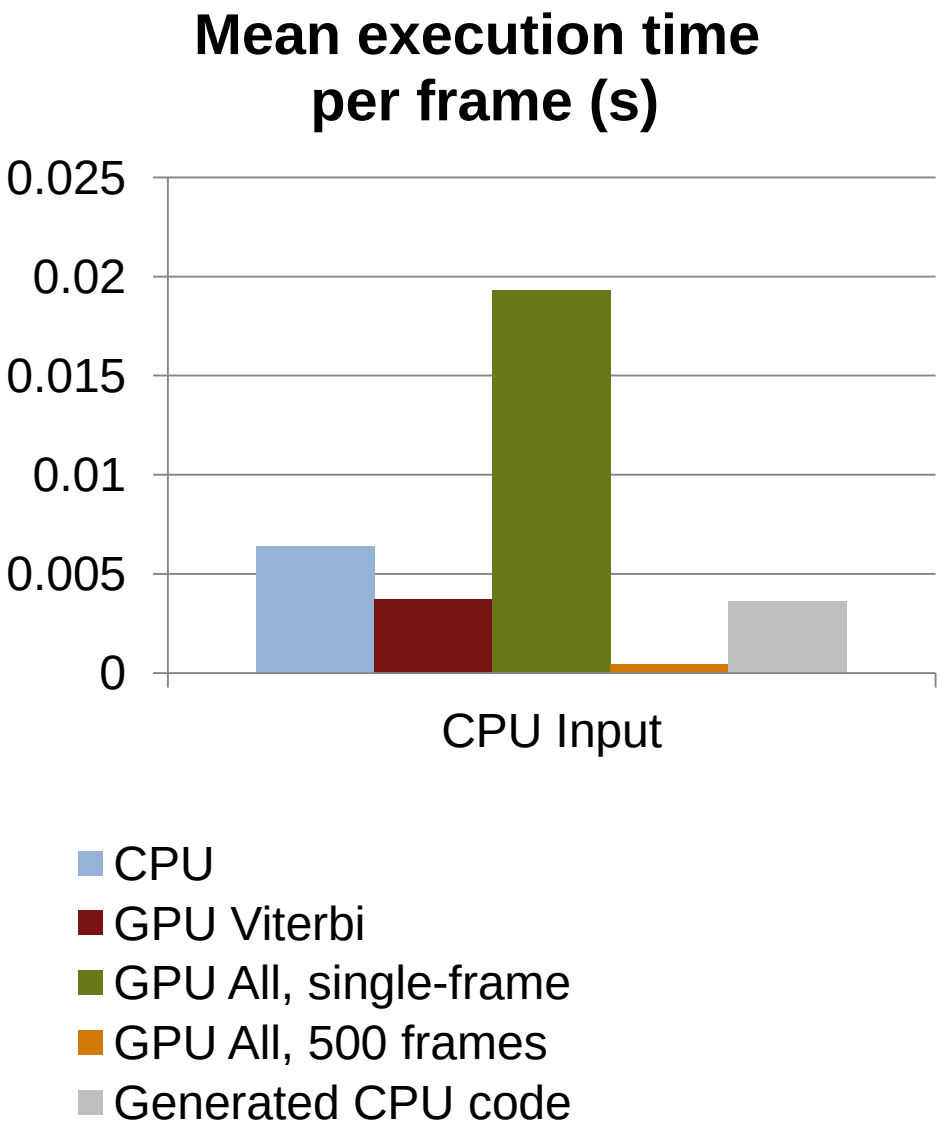
Digital Video Broadcast – Satellite (DVB-S) benchmark



- DVB-S is a similar system
  - uses different encoder/decoder pair than DVB-S.2
- The entire chain executes on the GPU
  - including message generation and validation
- Viterbi Decoder is implemented as a custom CUDA kernel
  - all others implemented using MATLAB GPU support

DVB-S Subset Benchmarks

- **DVB-S frame size is 1632 elements**
  - **single-frame performance on the GPU is slower than the CPU**
  - **multi-frame performance is much faster**



Conclusions

- The GPU can be a powerful tool for accelerating Bit Error Rate simulation in MATLAB
- Parallel Computing Toolbox allows a trade-off between work and performance
  - Implement the kernels with highest computational requirements as custom CUDA kernels
  - Implement kernels with lower computational requirements using MATLAB
- For best performance using the GPU, process multiple data frames simultaneously

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