Architecting High-Speed Data Streaming Systems

Sujit Basu
stream·ing [stree·ming] – verb

1. The act of transferring data to or from an instrument at a rate high enough to sustain continuous acquisition or generation.
Motivation for Data Streaming

• Ever-increasing amounts of data
• Record “everything” and play it back later
• DAQ, DSA, vision, modular instruments
• Hard drives: faster, bigger, and cheaper
• RAID hardware is ubiquitous and inexpensive
  • PCI Express, ExpressCard, USB, 1394, eSATA
• PCI Express provides higher, dedicated bandwidth
Applications Requiring Data Streaming

- RF Recording and Playback
- IF and Baseband Streaming
- Noise Mapping
- Digital Streaming

Spectral Monitoring:
Chengdu Huari Telecommunications Company

RF Record and Playback:
B&B Technologies

Noise Mapping:
Boeing
Key System Components

• Hardware Platform with High-Throughput and Low-Latency

• High-Speed Data Storage
  ▪ Hard Drives (HDDs)
  ▪ Solid-State Drives (SSDs)

• Software for Streaming to Disk at High Rates

• Streaming Front-End Instrumentation
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System Streaming Architecture – PXI

Controller

CPU

Chipset

Frontside Bus

Northbridge
(Memory & Graphics Controller)

Internal Bus

Southbridge
(IO Controller)

Ram

PCI Bus

HDD

Chassis

Segment 1: 5 Slots
Slots 2 to 6

Segment 2: 6 Slots
Slots 7 to 12

Segment 3: 6 Slots
Slots 13 to 18

PXI Slot1 Connector (PCI Bus)

PCI Bridge

PCI Bridge

PXI Slots

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Streaming to/from Controller Hard Drives

Controller

CPU

Chipset

Northbridge
(Memory and Graphics Controller)

Southbridge
(I/O Controller)

RAM

Frontside Bus

PCI Bus

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Segment 1: 5 Slots
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PXI Slot1 (PCI Bus)

PCI Bridge

PCI Bus

PXI Slots

PCI Bus

Stream to/from Controller Hard Drives

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PCI Express Overview

- Serial interconnect at **2.5 Gbits/s**
  - PCI transactions are packetized and then serialized
  - Low-voltage differential signaling, point-to-point, 8 B/10 B encoded
  - x1 (by 1) has bandwidth of **250 Mbytes/s per direction**
  - x16 (by 16) has bandwidth of **4 Gbytes/s per direction**

- Uses same software model as PCI
  - Ensures software compatibility

- Road map for longevity with Gen 2 clocking (5 Gbits/s)
System Streaming Architecture – PXI Express

PXI Express System

NI PXI-1045

NI PXI-8106

PCI Bus
132 MB/s

NI PXIe-1062Q

NI PXIe-8130

Total system slot bandwidth depends on controller/chassis combination

Four x4 PCI Express Links

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Streaming Architecture – PXI Express Controllers

NI PXIe-8130

CPU
AMD Turion 64 X2

Chipset
nVIDIA MCP55 Pro

Four independent x4 PCI Express Link
Each capable of 1 GB/s – Total bandwidth of 4 GB/s

Forwarded to Chassis

RAM

HDD
Streaming Architecture – PXI Express Controllers

NI PXIe-8108

- **CPU**: Intel Core 2 Duo
- **Graphics & Memory Controller**
- **HDD**
- **I/O Controller**

- Four x1 PCI Express Links
- Total System Bandwidth of 1 GB/s

Forwarded to Chassis

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### Streaming Architecture – PXI Express Chassis

**NI PXIe–1062Q**

Three x4 PCI Express Links
Each Capable of 1 GB/s Throughput

From Controller

**Slot Color Legend**
- PXI Slot
- PXI Express/Hybrid Slot
- PXI Express System Timing Slot

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NI PXIe-1075 Backplane

Four x4 PCI Express Links

Slot Color Legend
- Hybrid Slot
- PXI Express Slot
- PXI Express System Timing Slot
Key System Components

- Hardware Platform with High-Throughput and Low-Latency
- **High-Speed Data Storage**
  - Hard Drives (HDDs)
  - Solid-State Drives (SSDs)
- Software for Streaming to Disk at High Rates
- Streaming Front-End Instrumentation
Stream To/From Disk Rates

<table>
<thead>
<tr>
<th>Drive(s)</th>
<th>Max Rate: Write/Read (MB/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laptop</td>
<td>30  (NI PXIe-8106 internal drive; 5,400 RPM)</td>
</tr>
<tr>
<td>IDE</td>
<td>57  (Western Digital 160 GB; 7,200 RPM)</td>
</tr>
<tr>
<td>SATA</td>
<td>62  (Western Digital 160 GB; 7,200 RPM)</td>
</tr>
<tr>
<td>SATA</td>
<td>75  (Seagate Barracuda 250 GB; 7,200 RPM)</td>
</tr>
</tbody>
</table>

• Most hard drive manufacturers do not specify streaming rates
• Specifications beyond the interface (SATA, PATA, IDE) dictate hard drive performance
  • Seek times (ms)
  • Rotational speed (RPM)
  • Buffer size (MB)
  • Density
• Benchmarking is the only guarantee
Disk Performance

- Outer rim faster, inner rim slower
- 62 MB/s at outer rim, 36 MB/s at inner rim
- Windows OS allocates file space from outer rim inward
- True for most RAID arrays as well
Hard Drive Streaming Performance

- **Formatting**
  - Allocation unit size – the larger the better
  - Use “quick format”

- “**Write Caching**” must be turned ON

- Turn off “System Restore” and “Recycle Bin”

- File location on disk and fragmentation
Understanding SSDs
Performance versus Capacity

• Two types of SSD Drives: SLC and MLC

**Single-Level Cell (SLC)**

**Pros:** Performance, Life

**Cons:** Low-Capacity, Cost

**Multilevel Cell (MLC)**

**Pros:** Capacity, Cost

**Cons:** Performance, Life
Understanding SSDs
Performance versus Capacity

20 GB Write on 32 GB SLC SSD

160 GB Write on 256 GB MLC SSD
What Is RAID?

Redundant Array of Independent Drives, is a general term for mass storage schemes that split or replicate data across multiple hard drives.
Raid 0

RAID 0 → Striping without redundancy
• Improved speed over streaming to a single hard drive
• Unimproved system reliability
• Transparently supported by Windows OS
Raid 1

RAID 1 → Mirrored (redundancy)
- 100% data redundancy
- No write speed increase over single disk
- Highest overhead of all raid configurations
Raid 5

RAID 5 → Distributed parity
- Very efficient does not require additional disks
- Can only tolerate one drive failure
- Poor performance with small files
Raid 1+0

RAID 1+0 or 10 → Striping and mirroring

- Highest performance with data redundancy
- Can sustain multiple drive failures
- Configuration requires twice the hard drives
# Stream To/From Disk Rates

<table>
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<tr>
<th>Drive(s)</th>
<th>Write/Read (MB/s)</th>
<th>Rate Types</th>
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<tr>
<td>Laptop</td>
<td>30 (NI PXIe-8103 internal drive; 5,400 RPM)</td>
<td>Peak</td>
</tr>
<tr>
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<td>Peak</td>
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<tr>
<td>SATA</td>
<td>75 (Seagate Barracuda 7,200.10; 250 GB)</td>
<td>Peak</td>
</tr>
<tr>
<td>2 RAID</td>
<td>114/127 (NI PXI-8351 1U Rack Mount Controller)</td>
<td>Peak</td>
</tr>
<tr>
<td>4 RAID</td>
<td>200+/200+ (NI HDD-8263, NI 8353, NI 8260)</td>
<td>Sustained</td>
</tr>
<tr>
<td>12 RAID</td>
<td>600/600 (NI 8264 RAID Controller)</td>
<td>Sustained</td>
</tr>
</tbody>
</table>

Outer rim rates. Cannot be sustained across the whole drive.
Data Streaming Products

Rackmount (External)

NI HDD-8263
- 200 MB/s
- 1 TB
- More than 1 hour at 100 MS/s

NI HDD-8264
- 600 MB/s
- 3 TB
- More than 3 hours at 100 MS/s

In-Chassis (Internal)

NI HDD-8260
- 200 MB/s
- 1 TB
- More than 1.5 hour at 100 MS/s

- 3-slot wide, 4-drive
- SSD option (128 GB) available
- Software RAID

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NI 8260
In-Chassis High-Speed Storage Module

- For PXI Express systems
- 3-slot wide storage module
- 4-drive software RAID
- 200 MB/s
- HDD version: 1 TB
- SSD version: 128 GBs
Key System Components

• Hardware Platform with High-Throughput and Low-Latency

• High-Speed Data Storage
   Hard Drives (HDDs)
   Solid-State Drives (SSDs)

• **Software for Streaming to Disk at High Rates**

• Streaming Front-End Instrumentation
Using Data Streaming Products

- The RAID hard drives appear as logical partition in Windows OS
- LabVIEW 8.5.1 or later
  Win32 file I/O VIs
- LabVIEW 8.6 and later
  Built-in file VIs
- LabVIEW 2009
  Can Use LabVIEW 2009 TDMS
LabVIEW Programming Structure

\[ T_1 + T_2 \]
Use Multithreading

Create Queue

Acquisition Loop

Thread 1

File Write Loop

Thread 2

Loop Time = T_1 or T_2
Producer Consumer Loops

Create Queue → Acquire Data → Enqueue

File Write Data → Dequeue
Data Types

• Reduce file size
  - 1 I16 sample = 16 bits = 2 bytes
  - 1 DBL sample = 64 bits = 8 bytes = 4X increase in bandwidth
Demo 1

File Access Benchmarking Utility

Benchmark Configuration
- Drive: F:
- Sector Size: 512 bytes
- Desired File Size: 100M bytes
- Desired Transfer Block Size: 16M bytes
- Transfer Direction: Read
- File Access Mode: Unbuffered LabVIEW
- Iterations: 10

Start

Last Iteration Results
- File Size: 96M bytes
- Block Transfers: 6
- Transfer Speed: 295.886M B/sec

Results

Iteration Speeds (B/sec)
- 295.714M
- 295.039M
- 295.083M
- 294.479M
- 291.759M
- 287.425M
- 280.286M
- 288.288M
- 295.388M
- 295.205M

Average Speed (B/sec)
- 290.95M

Standard Deviation (B/sec)
- 3.5M

Stop
Key System Components

- Hardware Platform with High-Throughput and Low-Latency
- High-Speed Data Storage
  - Hard Drives (HDDs)
  - Solid-State Drives (SSDs)
- Software for Streaming to Disk at High Rates
- Streaming Front-End Instrumentation
Streaming Modules

PXle-6544/45 DIO
- 100/200 MHz
- 32 lines
- 1.2, 1.5, 1.8, 2.5, 3.3 V
- 660 MB/s

PXle-5442 Arb
- 100 MS/s
- 43 MHz, 16-bit
- 40 MHz DUC
- 200 MB/s

PXle-5122 Digitizer
- 2 channel
- 100 MS/s
- 100 MHz, 14-bit
- 400 MB/s
Streaming Modules

PXle-5673 VSG
• 85 MHz to 6.6 GHz
• 100 MHz Bandwidth
• 125 MS/s IQ Rate
• 500 MB/s

PXle-5663 VSA
• 10 MHz to 6.6 GHz
• 50 MHz Bandwidth
• 62.5 MS/s IQ Rate
• 250 MB/s
Streaming Modules

PXle-5450 IQ Generator
• 400 MS/s, 16-bit, dual-channel
• 145 MHz
• 600 MB/s dual-channel
• 360 MB/s single-channel

PXle-5622 IF Digitizer
• 150 MS/s, 16-bit
• 3-250 MHz
• 60 MHz DDC
• 300 MB/s
Streaming Modules

**PXle-8234 GigE Interface**
- Dual-port gigabit Ethernet
- NI Vision software
- 250 MB/s
Streaming Performance

- Most operations are possible with a direct link to the PXI Express controller (no switches)
- Chassis and controller set maximum system bandwidth
- Module location and type (input or output) are critical factors
Instrument Behavior: Input

Memory

Switch/Bridge/Chipset

Switch/Bridge/Chipset

Input Device

Data

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Instrument Behavior: **Output**

- **Memory**
- **Switch/Bridge/Chipset**
- **Switch/Bridge/Chipset**
- **Output Device**

**Events:**
- **Read Request**
- **Data**
High-Level Guidelines

• Streaming devices should be given their own dedicated link or switch, if possible
• RAID arrays should be the only streaming device on a dedicated controller link, whether or not they are behind a switch
• Modules with opposite streaming direction (input and output) should not be grouped behind the same switch
• Devices based on PXI Express NI-DAQmx (small onboard memory) should share their own switch

Lower than 400 MB/s aggregate bandwidth (input + output); these should not be a problem
A High-Performance Application

Controller
3.2 GB/s

CPU

Memory

PCI Express Switch
NI PXIe-5122
NI PXIe-5450

PCI Express Switch
NI PXIe-5122
NI PXIe-5450

PCI Express Switch
NI PXI-5122
NI PXIe-5450

PCI Express Switch
NI PXI-5122
NI PXIe-5450

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Demo 2

Data Streaming to Digital to Analog Converter (DAC)

Power Supply to DAC
NI PXI-4110
Triple-Output Programmable DC Power Supply

Instrument Descriptor
- NI PXI-4110
- Voltage level Ch0: 2.5
- Voltage level Ch1: 3.3

Resource Name
- 65650
- Sample Clock: 100M

High-Speed DIO to DAC
NI PXIe-6545
Digital Waveform Generator/Analyzer

DAC

Digitizing Analog Output from DAC
NI PXIe-5122
High-Speed Digitizer

Resource Name
- 5122e
- Min Sample Rate: 500M
- Vertical Range: 2V

High-Speed Data to HSDIO
NI 8260
Intrinsic High-Speed Storage Module

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Questions?