EECS Berkeley EE249
LabVIEW Framework

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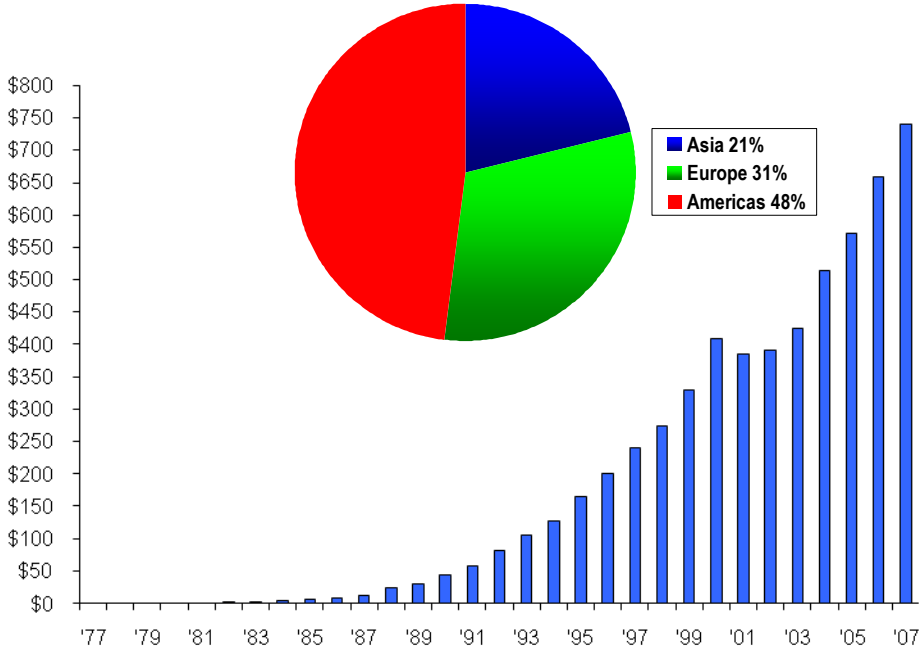
Principal Architect
LabVIEW Platform & Real Time Group

Agenda

- Overview of NI Tools
- LabVIEW
  - Intro
  - Framework
  - Parallel programming
    - From multi-core to many-core

National Instruments Profile

- Leaders in Computer-Based Measurement and Automation
- Strong Track Record of Growth and Profitability
- $740 MM Revenue in FY2007
- Past nine consecutive years voted *Fortune's* 100 Best Companies to Work For in America
- Headquartered in Austin, Texas
- More than 4,000 employees; operations in 40+ countries



Diversity of Customers

- Customers are mainly domain experts, scientists and engineers
- Top 100 customers ≈ 35% of revenue
- More than 25,000 customers in more than 90 countries
- 95% of Fortune 500 manufacturing companies have adopted Virtual Instrumentation

Diversity of Industries

Telecom

Automotive

Semiconductors

Electronics

Computers

ATE

Military/Aerospace

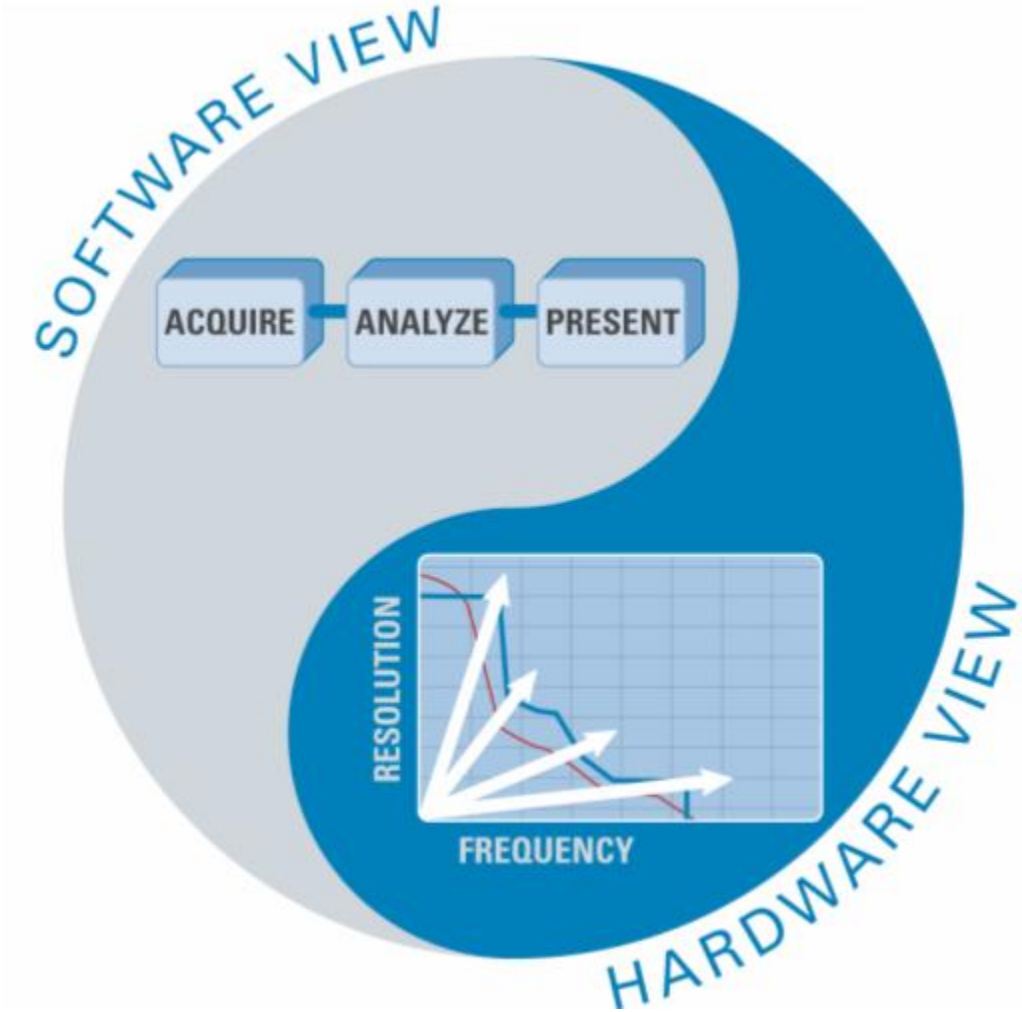
Advanced Research

Petrochemical

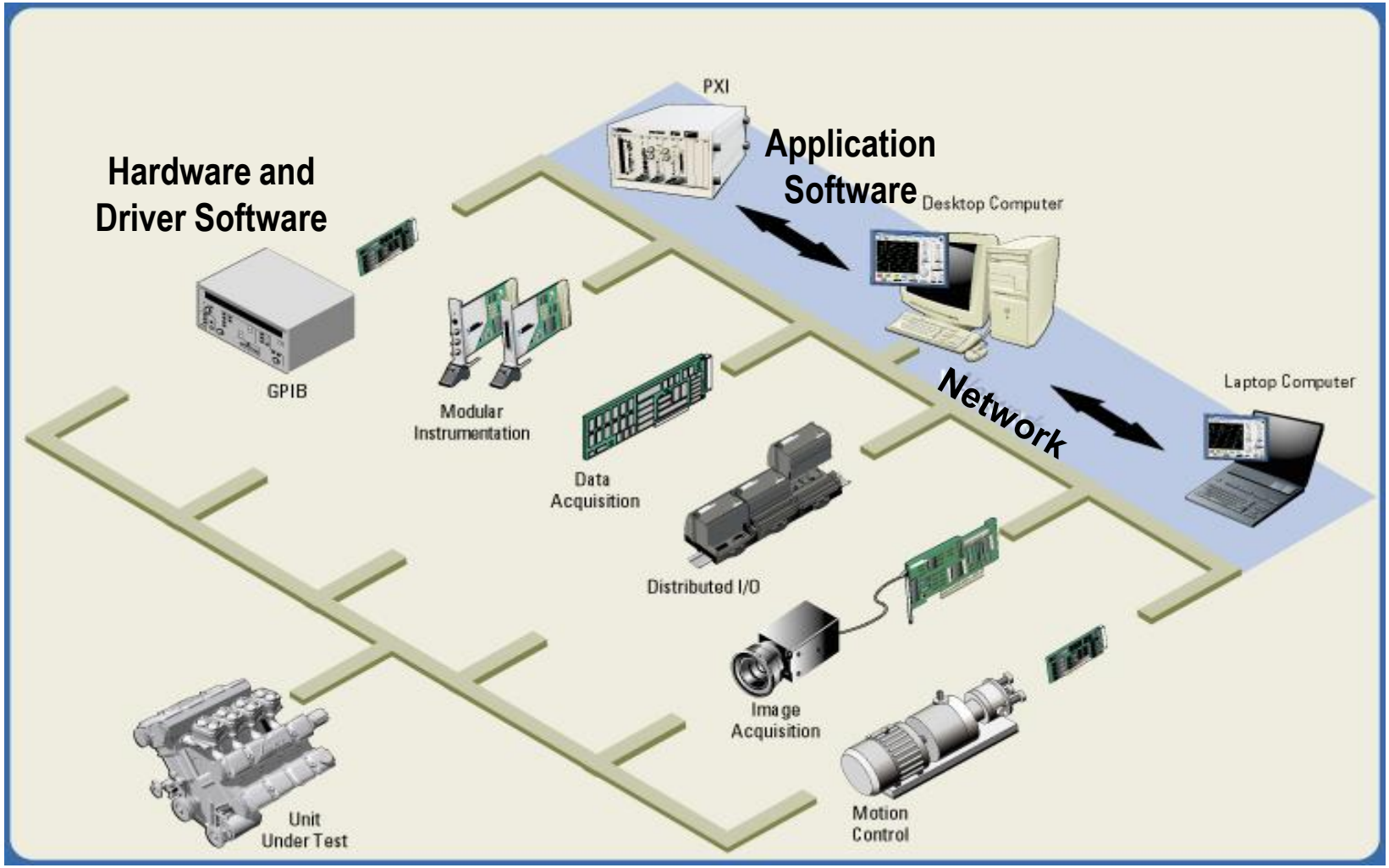
Food Processing

Textiles

Virtual Instrumentation



Virtual Instrumentation

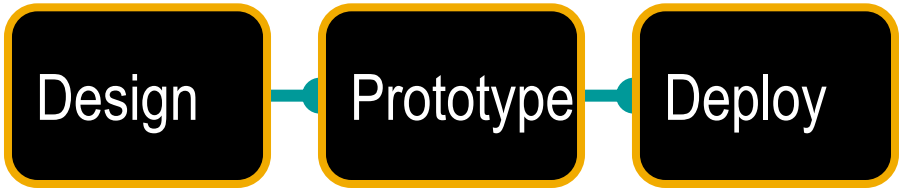


Virtual Instrumentation Applications

- **Analysis and Design**
  - Simulation
  - Signal and Image Processing
  - Embedded System Programming
    - (PC, DSP, FPGA, Microcontroller)
  - Prototyping
  - And more…
- **Control**
  - Automatic Controls and Dynamic Systems
  - Mechatronics and Robotics
  - And more…
- **Measurement/Test**
  - Circuits and Electronics
  - Measurements and Instrumentation

…

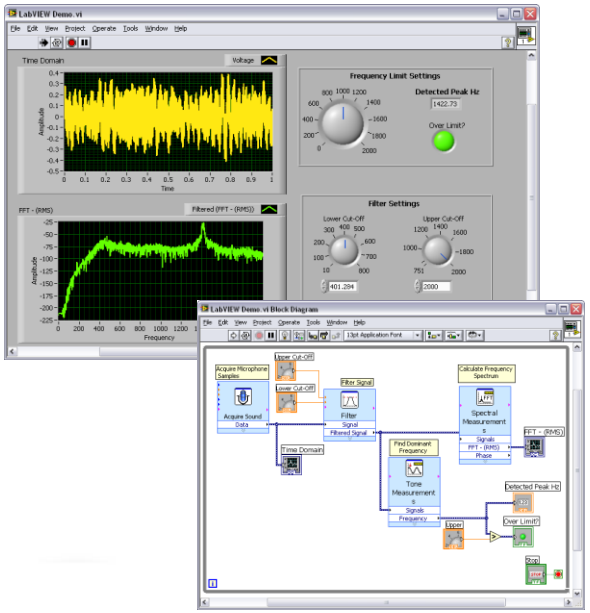
A single graphical development platform

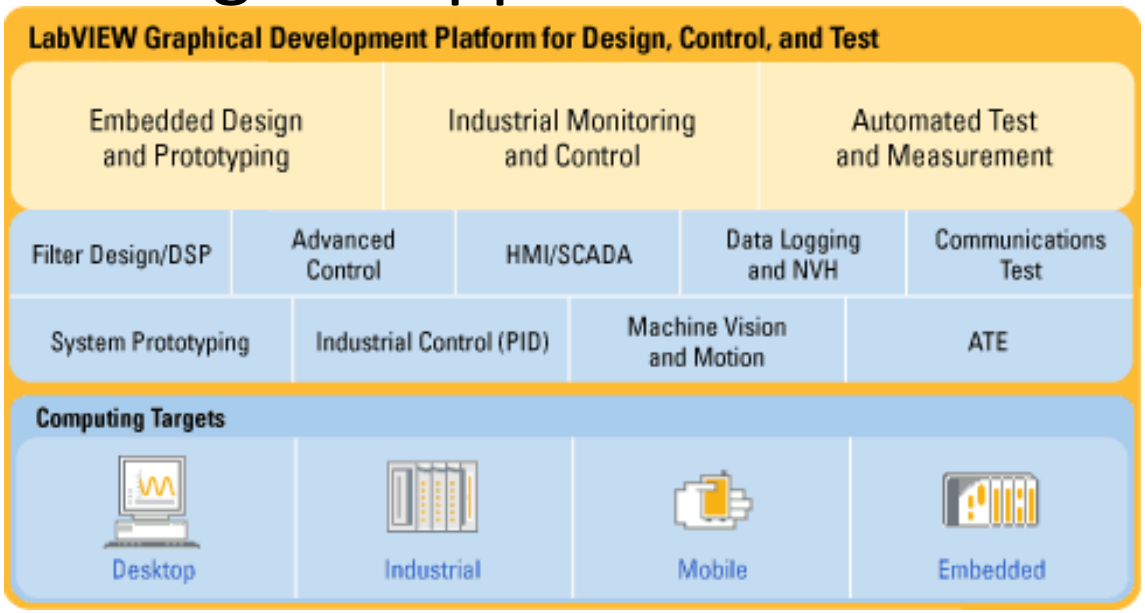


NATIONAL INSTRUMENTS LabVIEW™

LabVIEW Graphical Development System

- Graphical Programming Environment
- Compile code for multiple OS and devices
- Useful in a broad range of applications

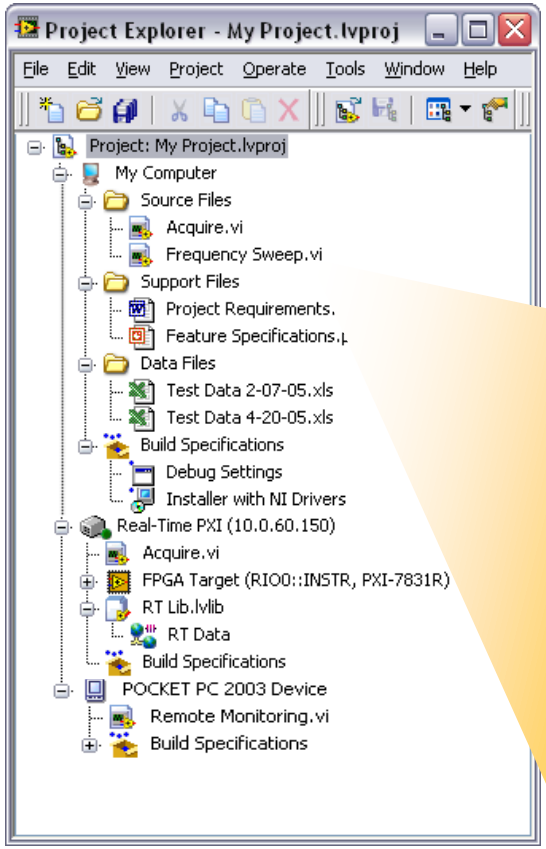




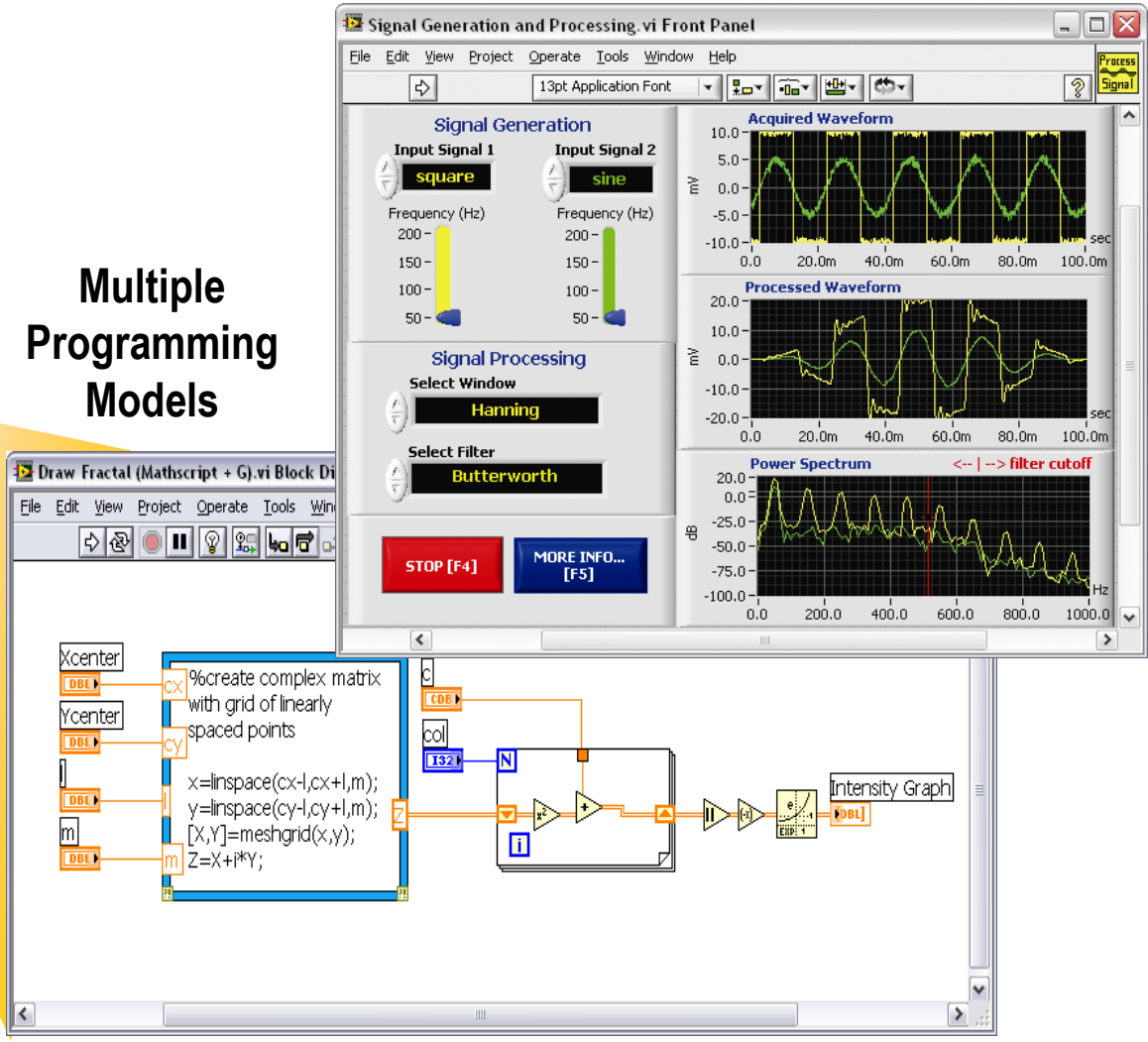
LabVIEW

- LabVIEW Background and Intro
- Facets
  - Measurement and Automation
    - (Instrument Control, I/O, DAQ, etc.
  - General purpose computing environment for scientists and engineers
  - Modeling Environment
  - Framework for Domain Experts
  - Embedded Development Environment
  - Framework for Parallel Programming Techniques

LabVIEW 8.6

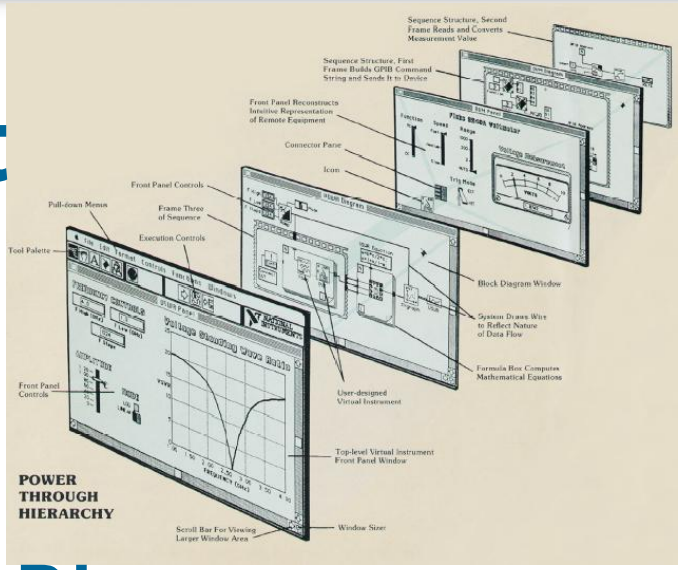


Multiple Programming Models

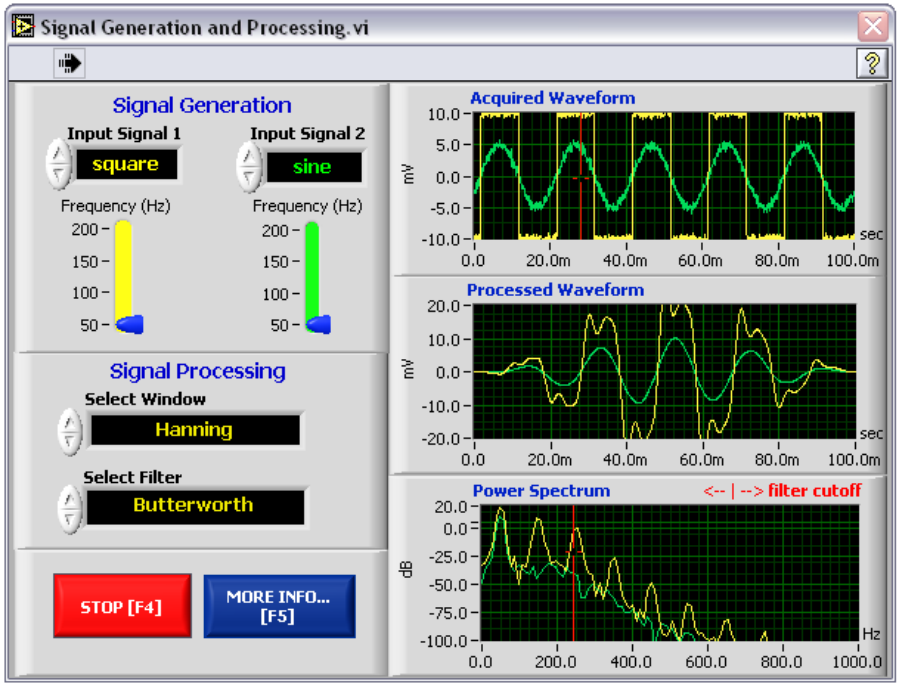


Distributed Multi-core Systems

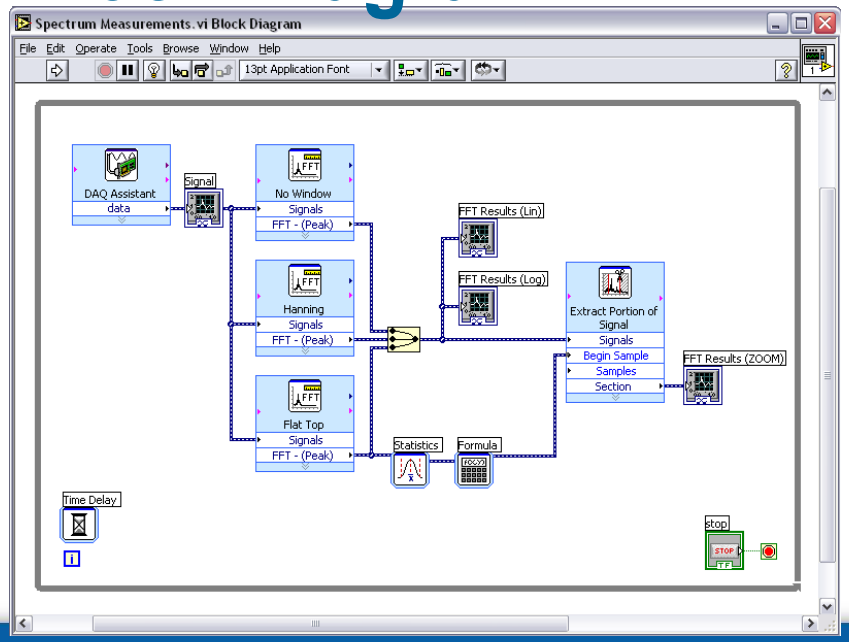
LabVIEW Virtual Instrument



Front Panel



Block Diagram



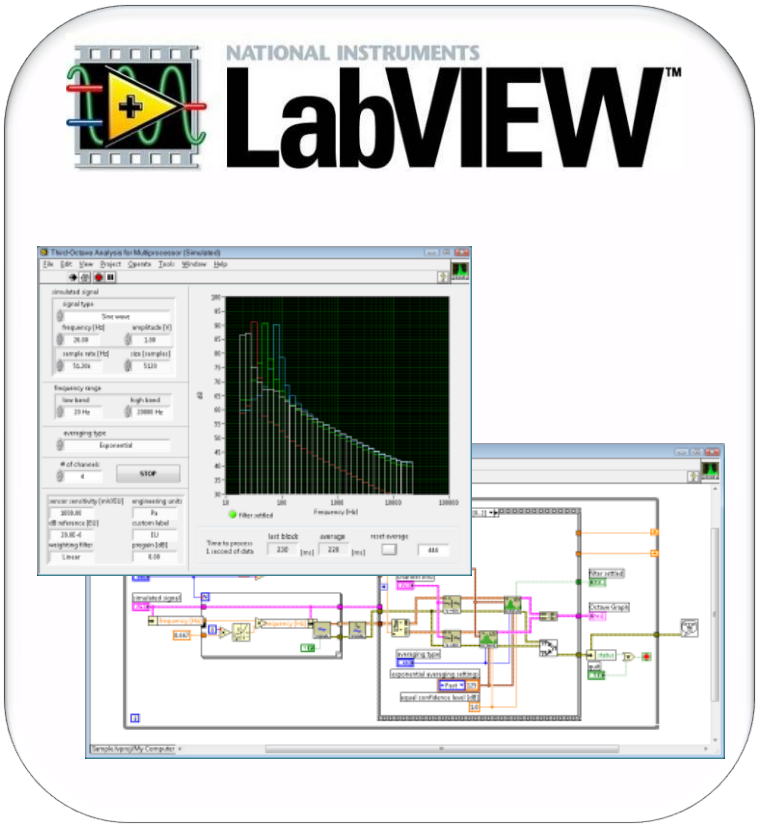
Introduction to LabVIEW and Dataflow

The G (LabVIEW) Language Model

- Homogenous dataflow language
  - Structured case (switch, select), loops, timed specs
    - “Structured dataflow”
- Turing complete
- Run-time scheduling
  - Inherently parallel language
- Synthesizable language
  - Direct compilation to software binaries on host processors
  - Embedded Processors (via C)
  - To FPGAs (via VHDL)

Section Outline: LabVIEW and Dataflow

1. Introduction to the LabVIEW environment
2. Functions and hierarchy
3. Dataflow and parallelism

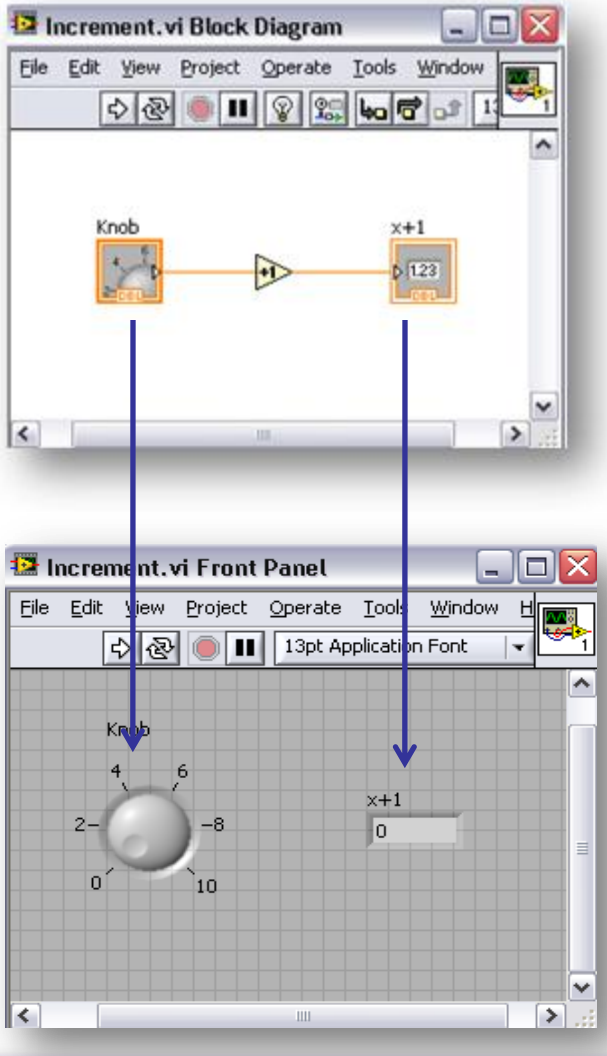


What is LabVIEW?

- Programming language: graphical programming based on structured dataflow
- Complete development environment: project explorer, debugging tools, source code control, and more

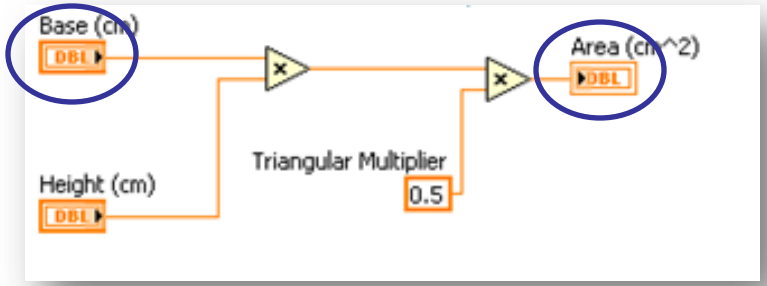
Parts of a LabVIEW Application

- Block diagram shows graphical source code
- Front panel contains graphical user interface (GUI) items (connected to source code)



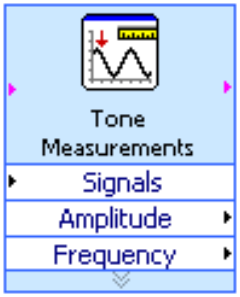
Block Diagram: Source Code

- Block diagram can contain functions, structures, and constants
- Analogous to functions, subroutines, flow control elements, and constants in text-based languages
- Terminals represent inputs and outputs

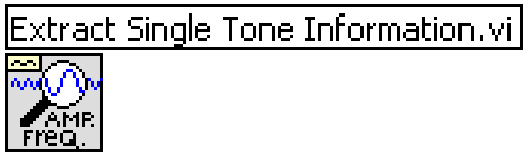


3 Types of Functions (from the Functions Palette)

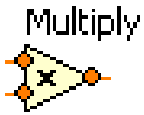
Express VIs: interactive VIs with configurable dialog page (blue border)



Standard VIs: modularized VIs customized by wiring (customizable)



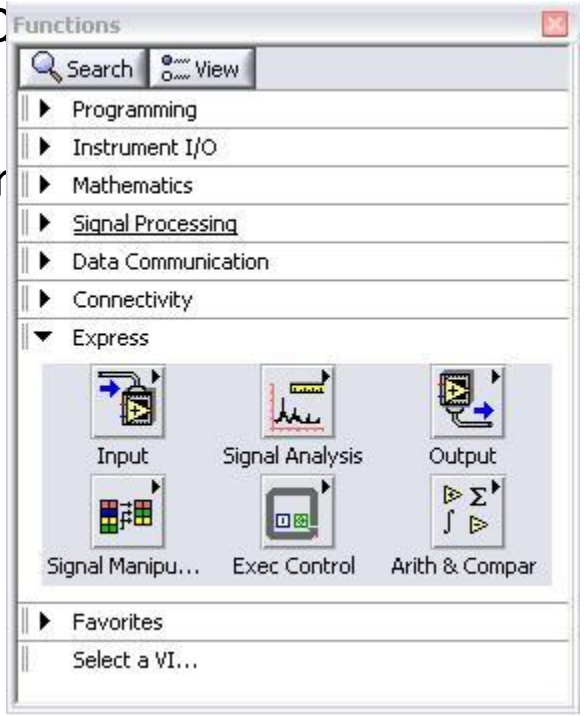
Functions: fundamental operating elements of LabVIEW; no front panel or block diagram (yellow)



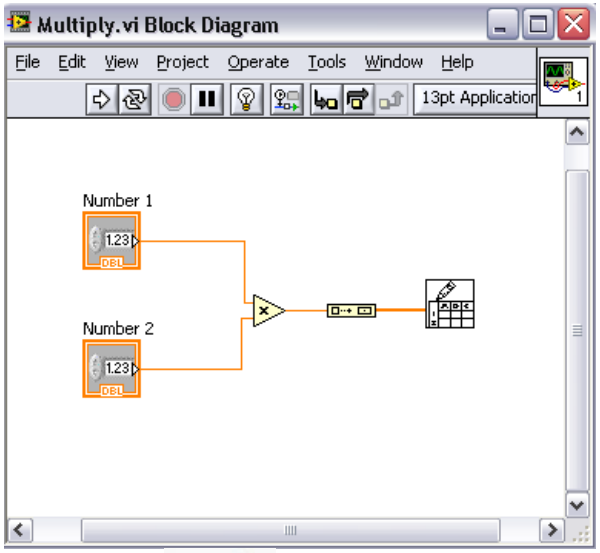
What Types of Functions are Available?

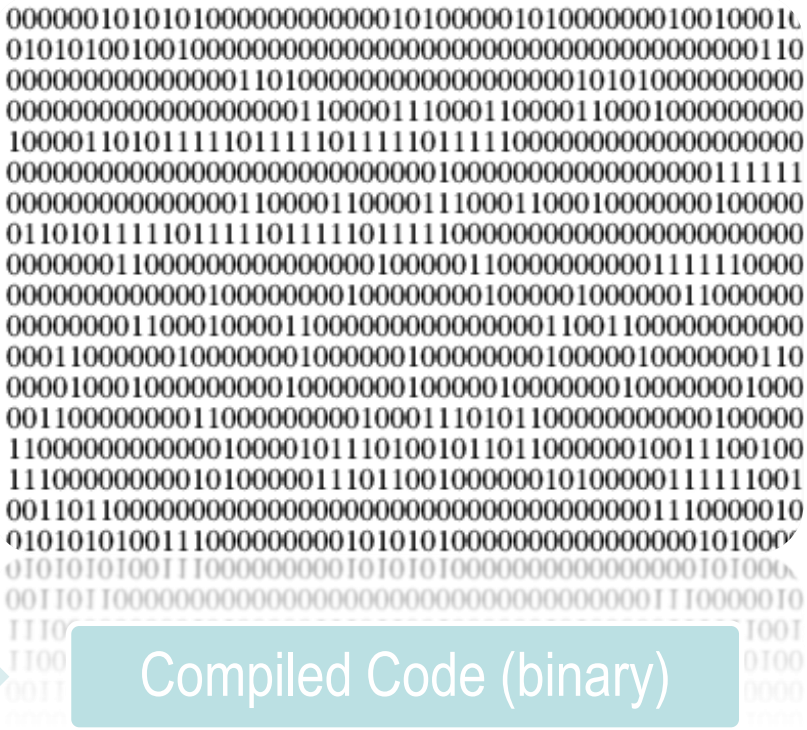
- **Input and Output**
  - Signal and Data Simulation
  - Acquire and Generate Real Signals with DAC
  - Instrument I/O Assistant (Serial & GPIB)
  - ActiveX for communication with other progr
- **Analysis**
  - Signal Processing
  - Statistics
  - Advanced Math and Formulas
  - Continuous Time Solver
- **Storage**
  - File I/O

Express Functions Palette



Cross-Platform Graphical Programming

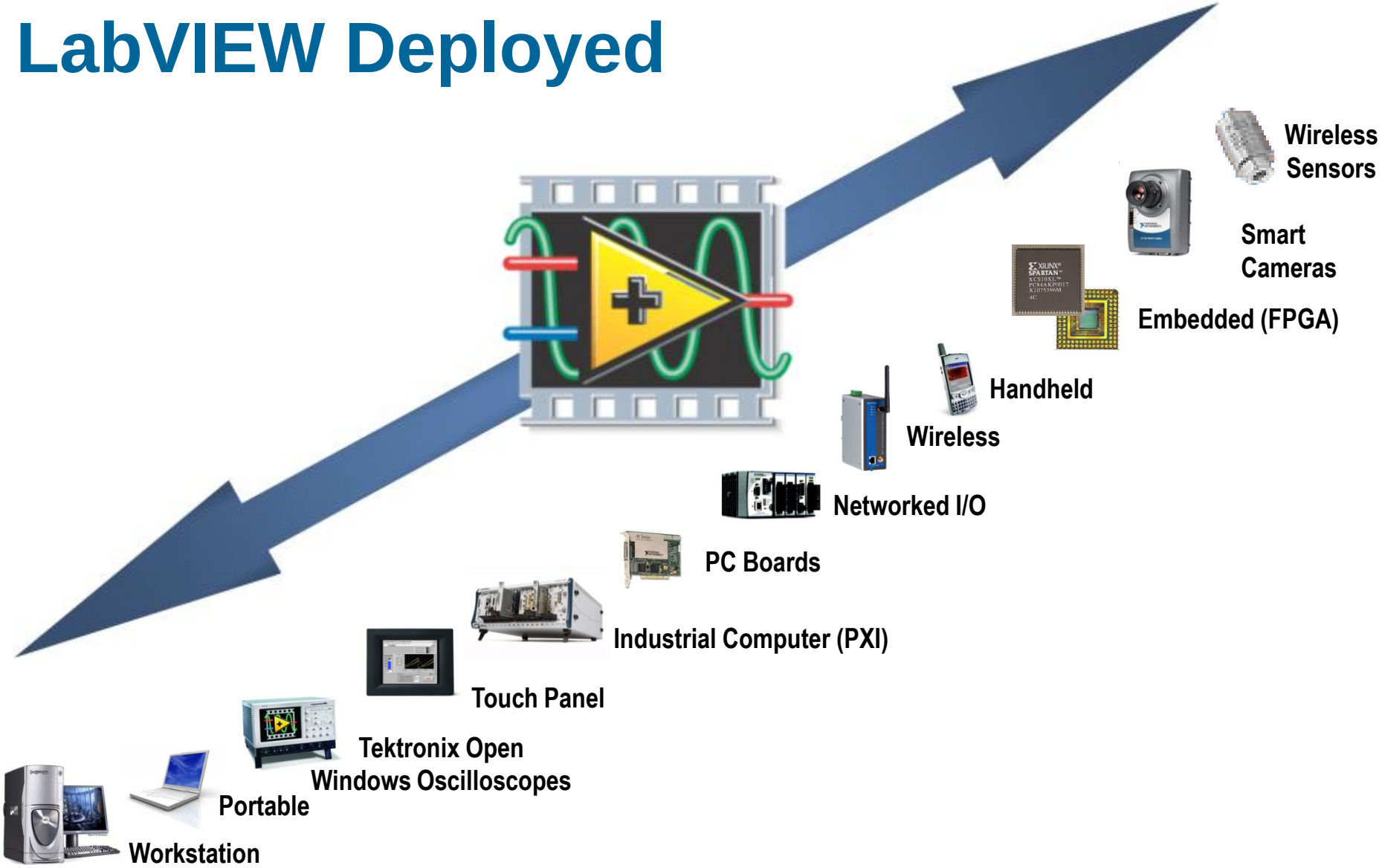




Graphical Source Code

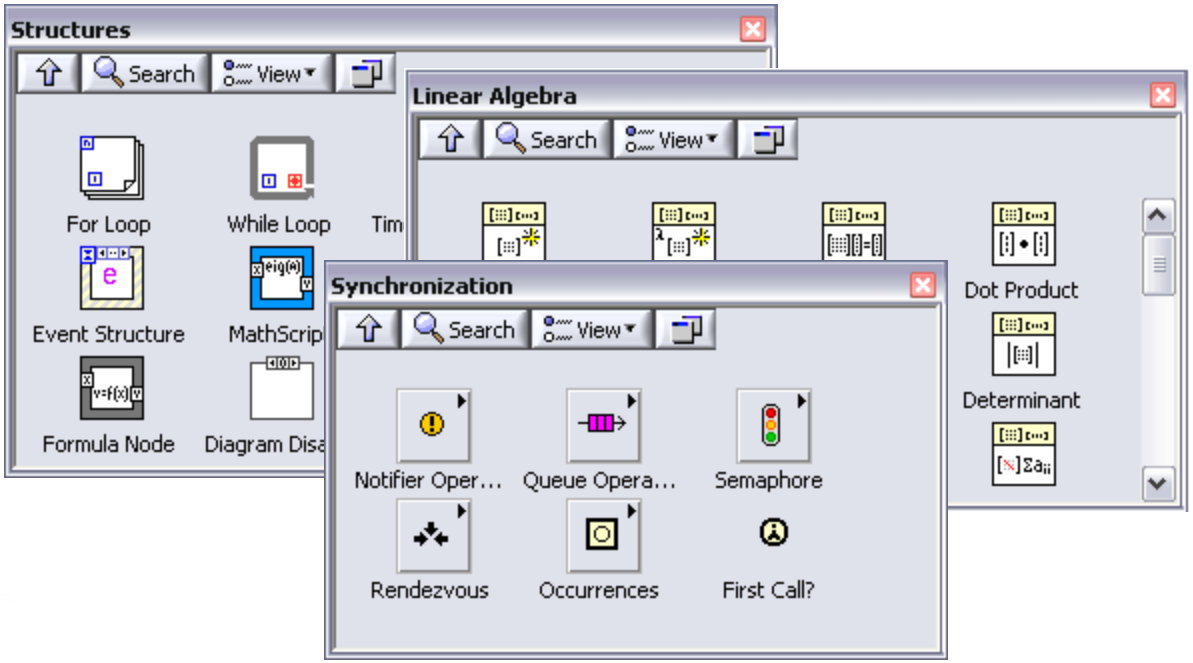
Compiled Code (binary)

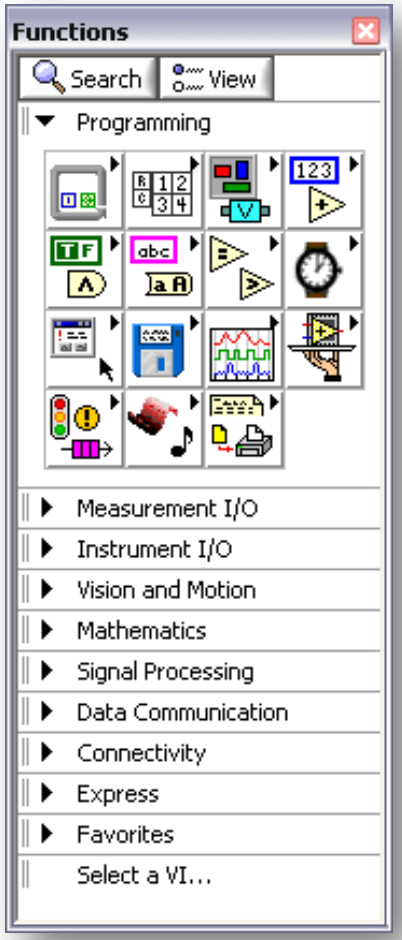
LabVIEW Deployed



Block Diagram: Functions Palette

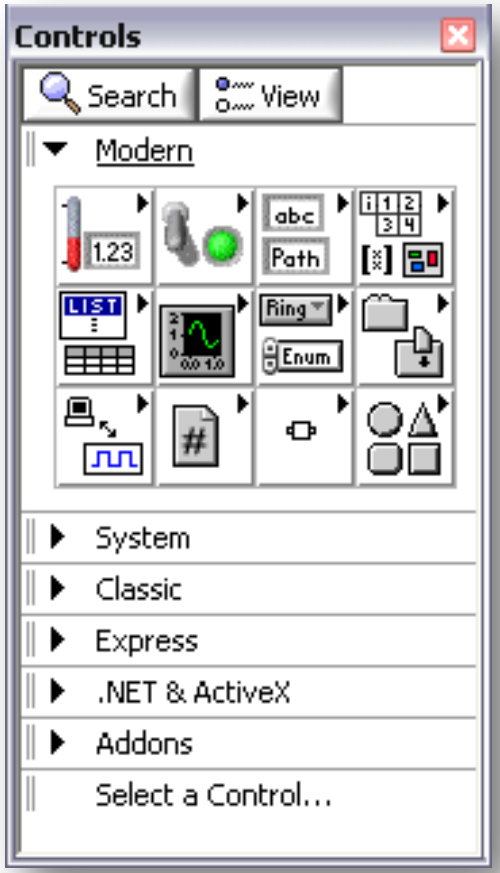
- Contains programming structures and functions
- Contains specialized IP, including math libraries built on Intel Math Kernel Library (MKL)





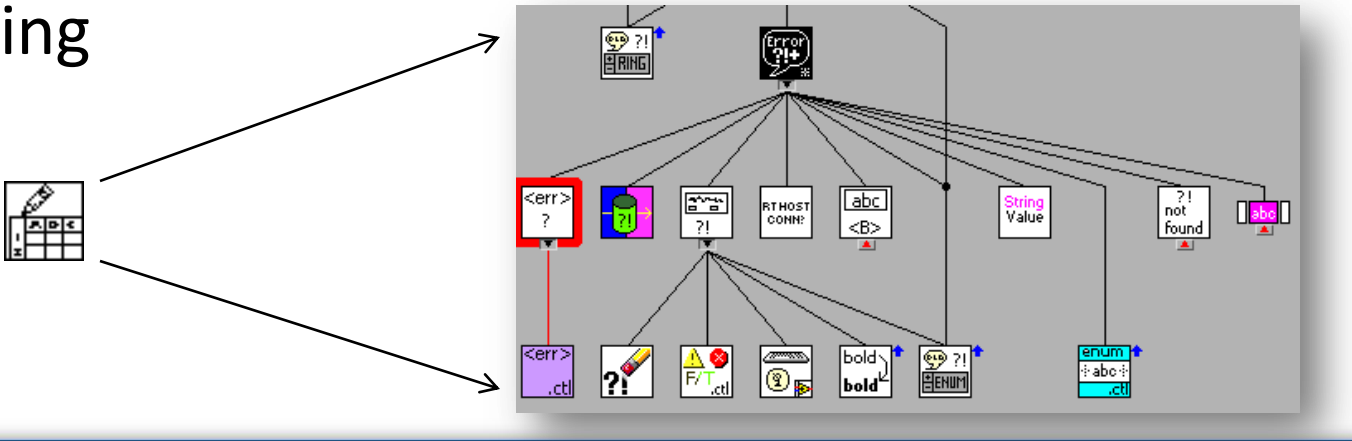
Front Panel: Controls Palette

- Controls (inputs): menus, text entry, selectors, buttons, etc.
- Indicators (outputs): graphs, LEDs, charts, and other displays



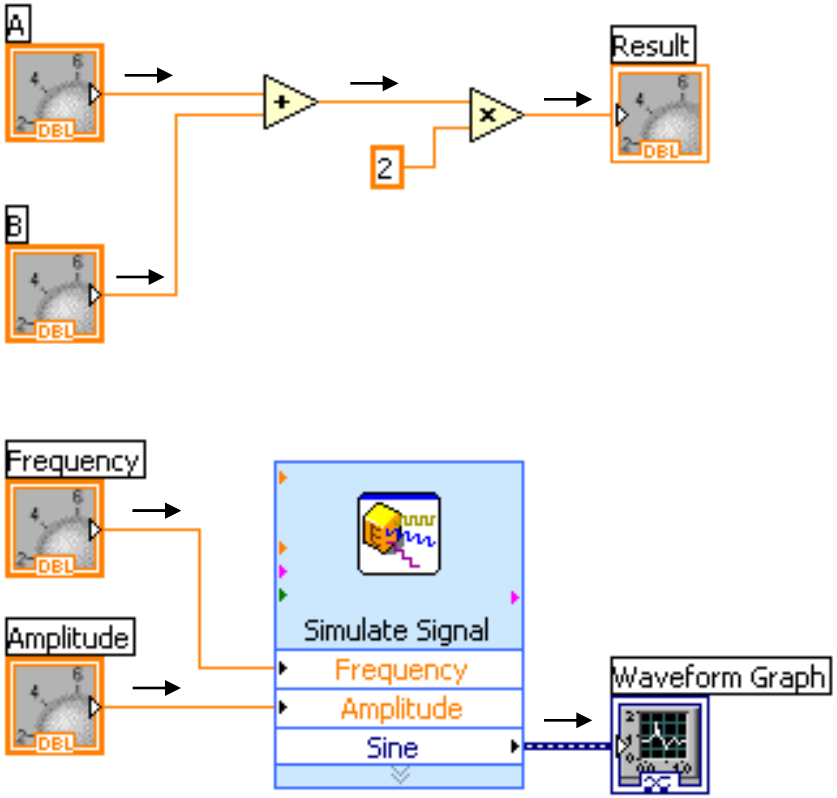
Hierarchy in LabVIEW

- A LabVIEW subVI is a VI that is called inside of another VI
- A subVI's inputs and outputs (parameters) are exposed and accessed on the block diagram
- Similar to a function or subroutine in text-based programming



Dataflow Programming

- Block diagram execution
  - Dependent on the flow of data
  - Block diagram does NOT execute left to right
- Node executes when data is available to ALL input terminals
- Nodes supply data to all output terminals when done

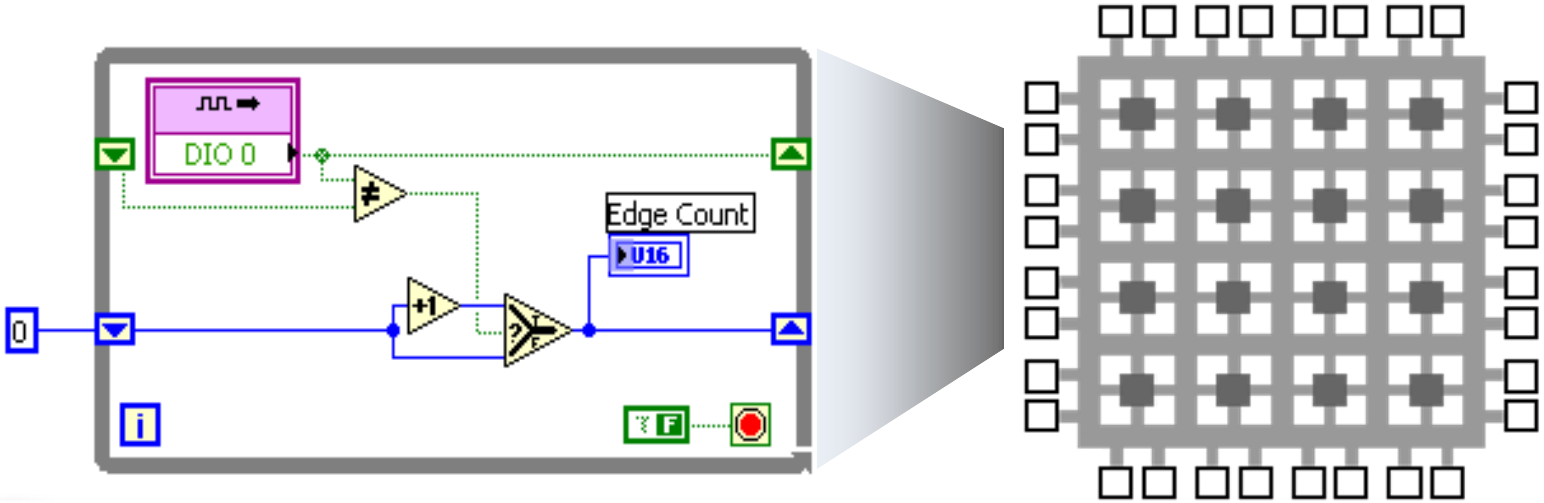


Dataflow and Parallel Execution

- Dataflow programming means inherent parallelism in your application
- Parallel code sections in a dataflow program can be easily visualized

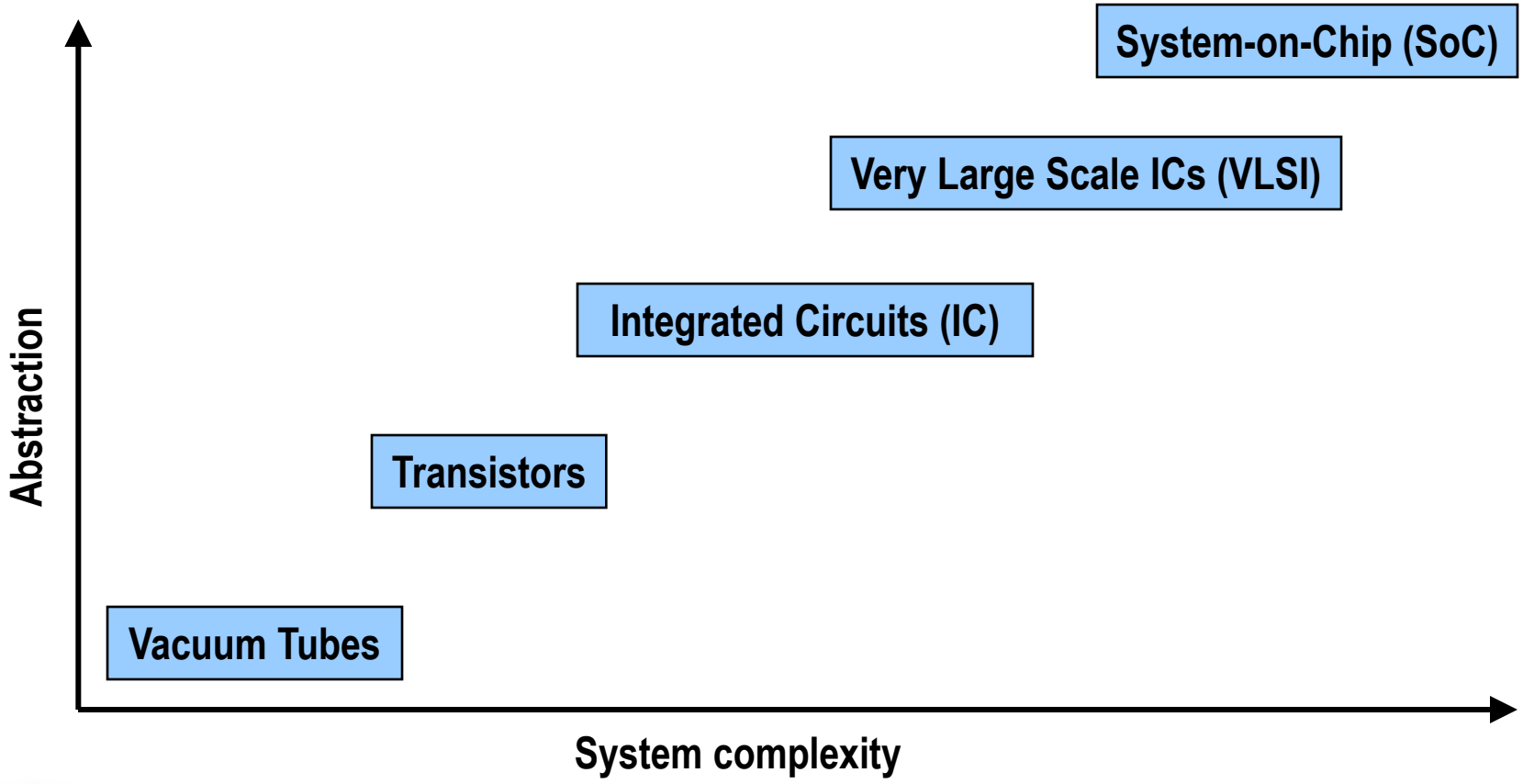
Dataflow and Parallel Execution

- Program massively parallel hardware with LabVIEW FPGA
- Same approach as programming CPUs, only code executes directly in hardware

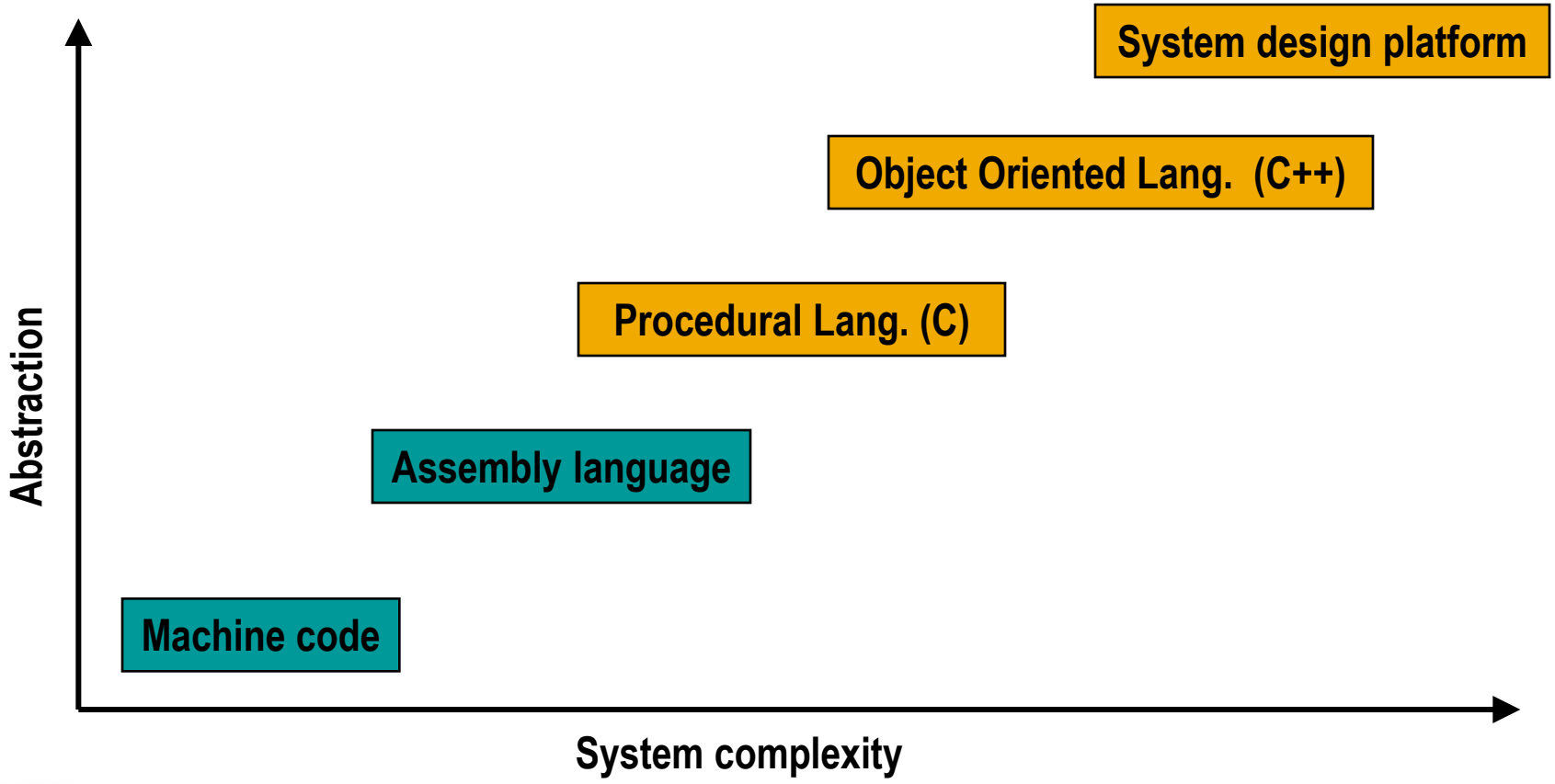


Simple LabVIEW G Demo

Increasing Levels of Hardware Abstraction

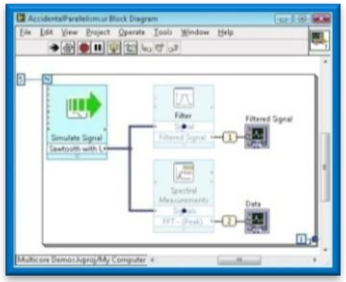


Increasing Levels of Software Abstraction

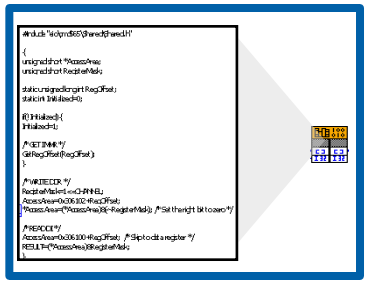


High-Level Development Tools

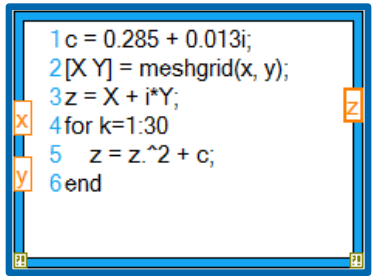
Data Flow



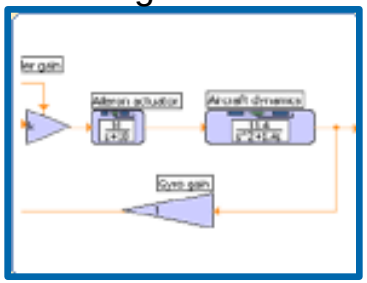
C Code



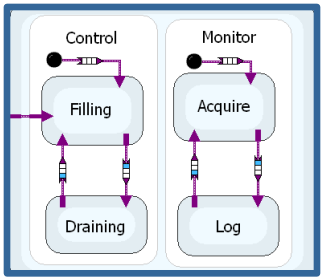
Textual Math



Modeling



Statechart



NATIONAL INSTRUMENTS

LabVIEW™

Graphical System Design Platform

Desktop Platform

Linux®

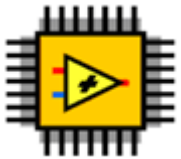
Macintosh

Windows

Embedded Platform

Real-Time

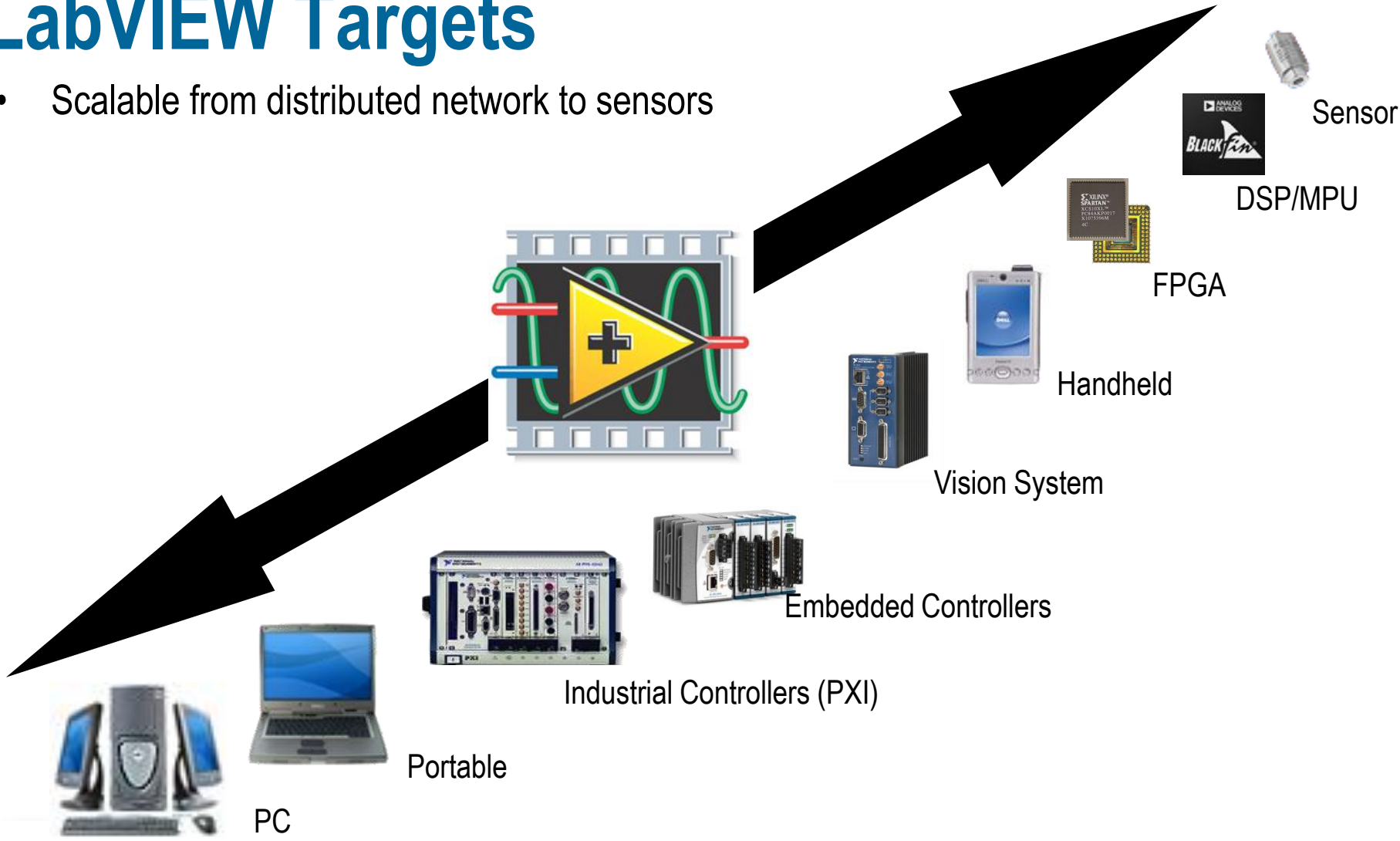
FPGA



Micro

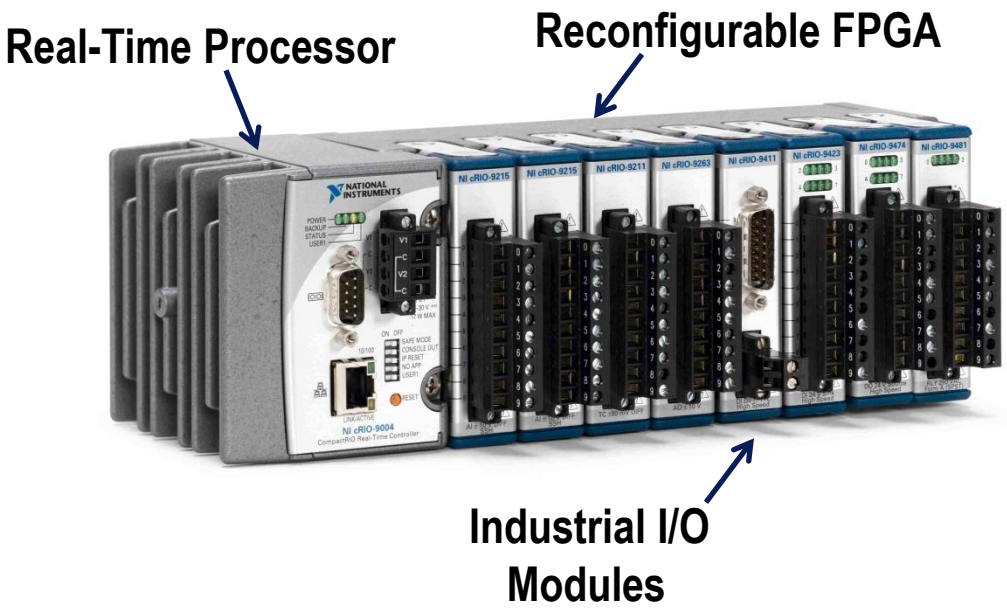
LabVIEW Targets

- Scalable from distributed network to sensors



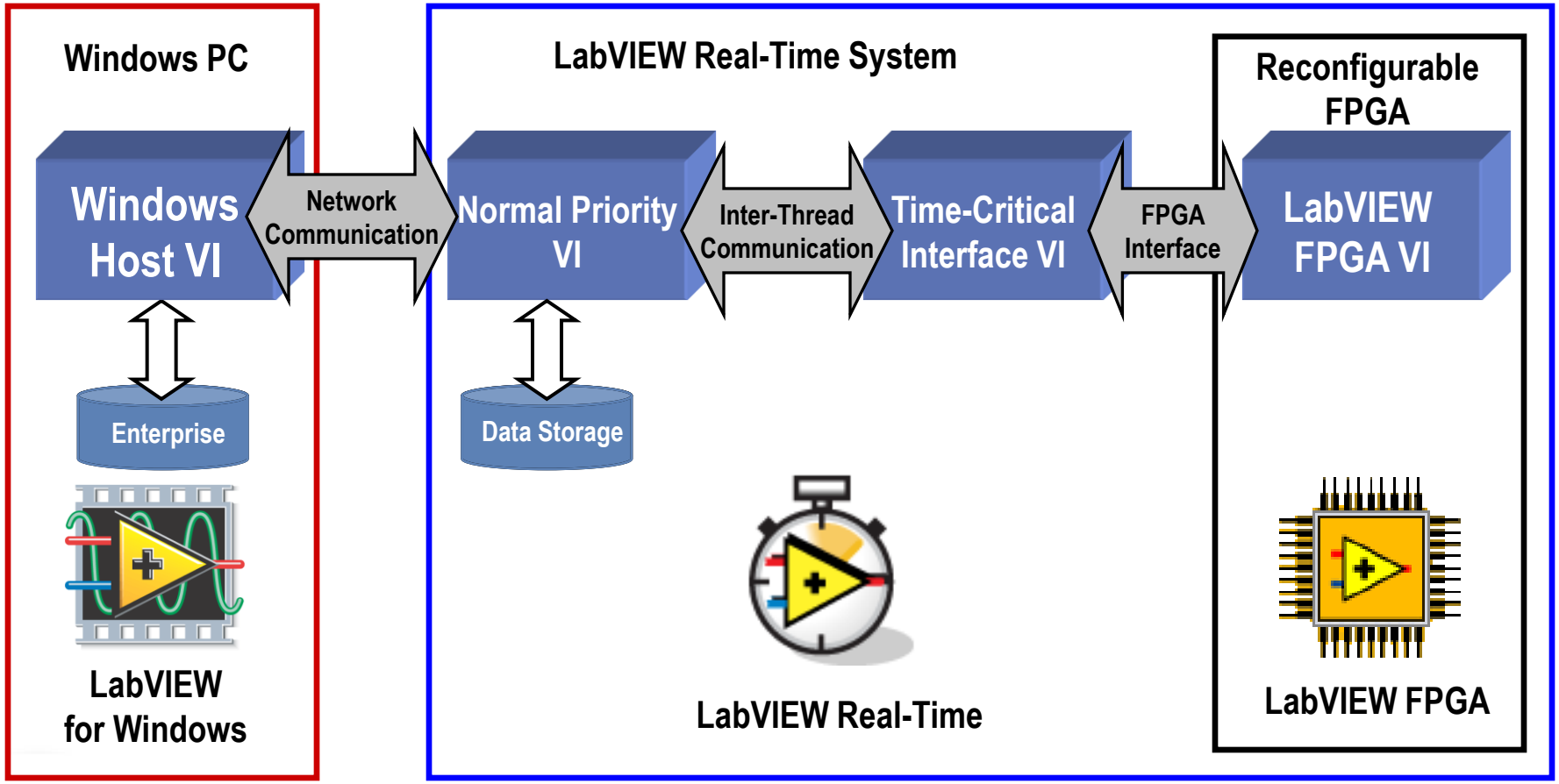
LabVIEW on cRIO - HW

CompactRIO

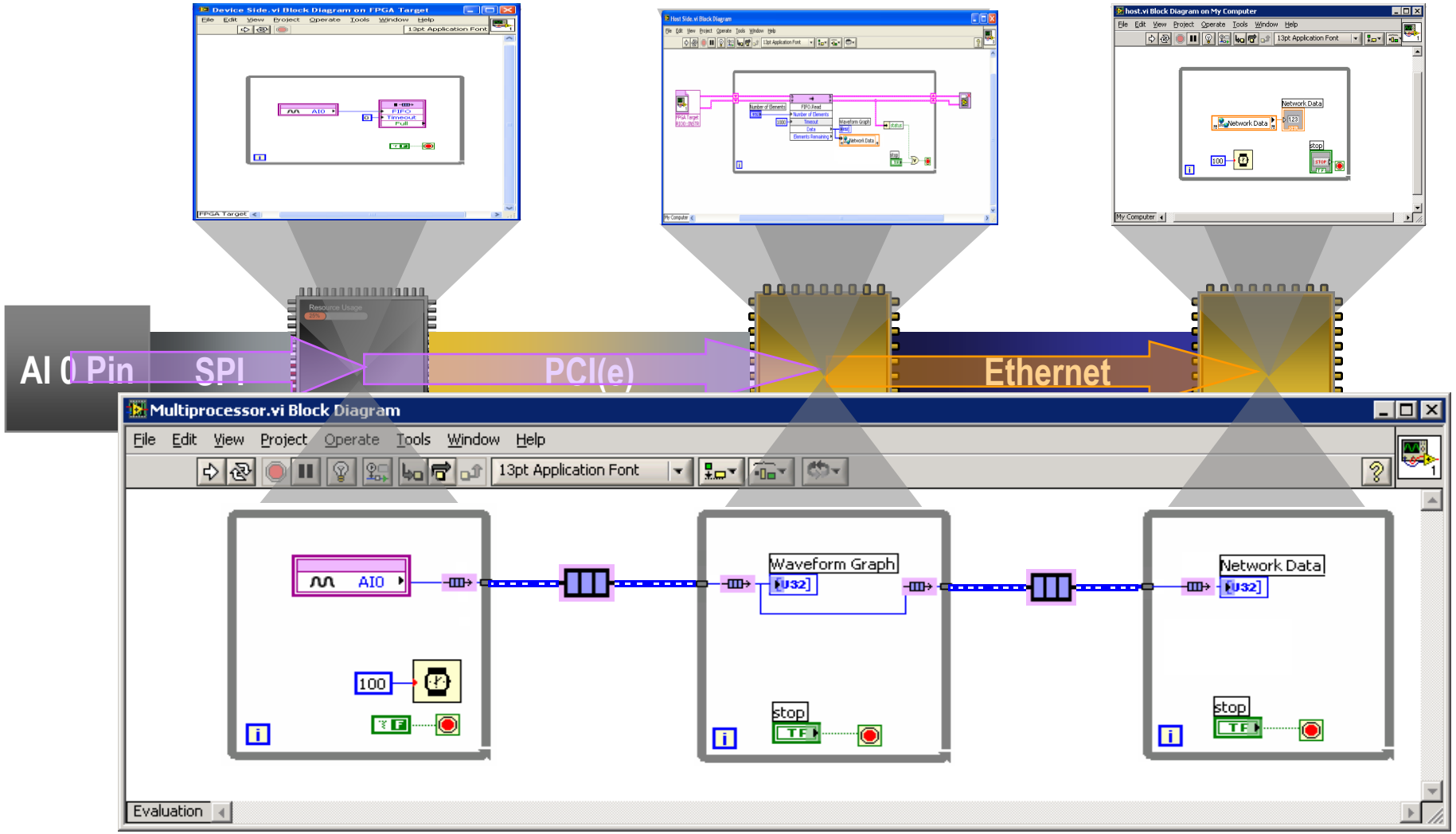


- **Industrial I/O Modules** with built-in signal conditioning for direct connection to sensors/actuators
- **Reconfigurable FPGA** for high-speed and custom I/O timing, triggering, control
- **Real-Time Processor** for deterministic, stand-alone operation and advanced analysis

LabVIEW on cRIO – Logical Diagram

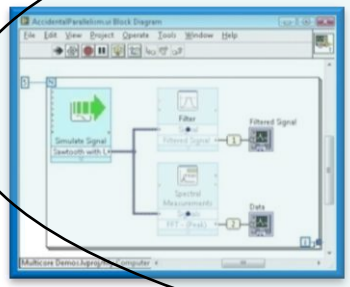


LabVIEW on cRIO – SW and Some Ideas



High-Level Development Tools

Data Flow

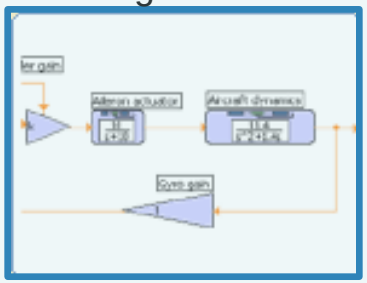


C Code

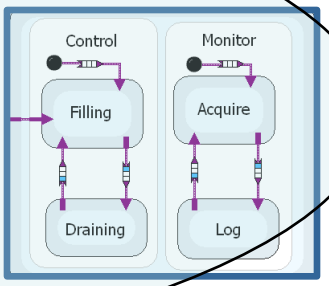
Textual Math

```
c = 0.285 + 0.013i;
[X Y] = meshgrid(x, y);
z = X + i*Y;
for k=1:30
    z = z.^2 + c;
end
```

Modeling



Statechart



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Graphical System Design Platform

Desktop Platform

Linux®

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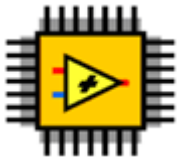
Embedded Platform

Real-Time

FPGA



Micro

LabVIEW as a Framework

- Demo Express VI
- Demo Vision Assistant
  - Metal example
- Demo Motion Assistant

Textual Math in LabVIEW

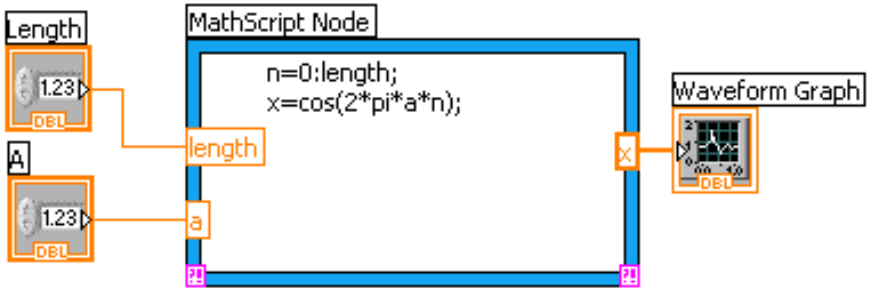
- Integrate existing scripts with LabVIEW for faster development
- Interactive, easy-to-use, hands-on learning environment
- Develop algorithms, explore mathematical concepts, and analyze results using a single environment
- Freedom to choose the most effective syntax, whether graphical or textual within one VI

Supported Math Tools:

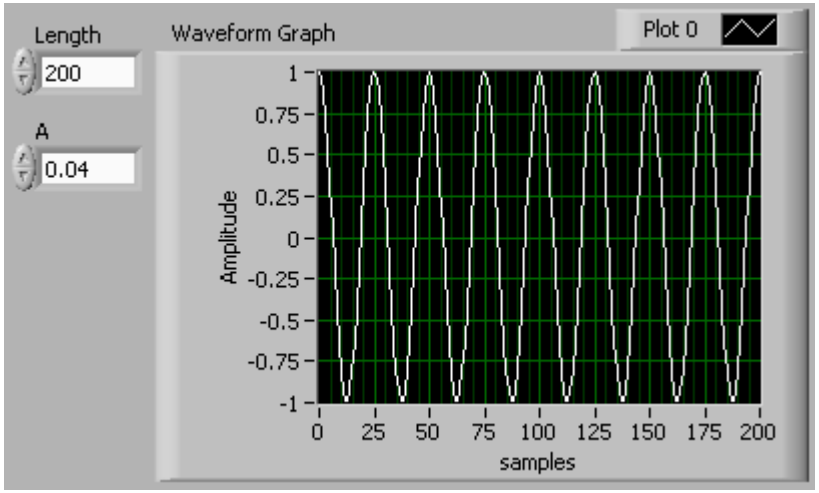
MathScript script node	MathSoft software
Mathematica software	MATLAB® software
Maple software	Xmath software

Math with the MathScript Node

- Implement equations and algorithms textually
- Input and Output variables created at the border
- Generally compatible with popular m-file script language
- Terminate statements with a semicolon to disable immediate output



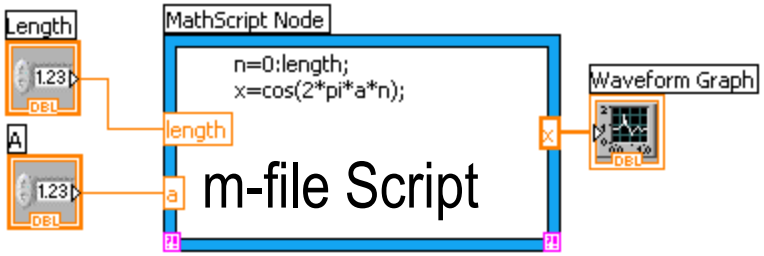
(Functions»Programming»Structures»MathScript)

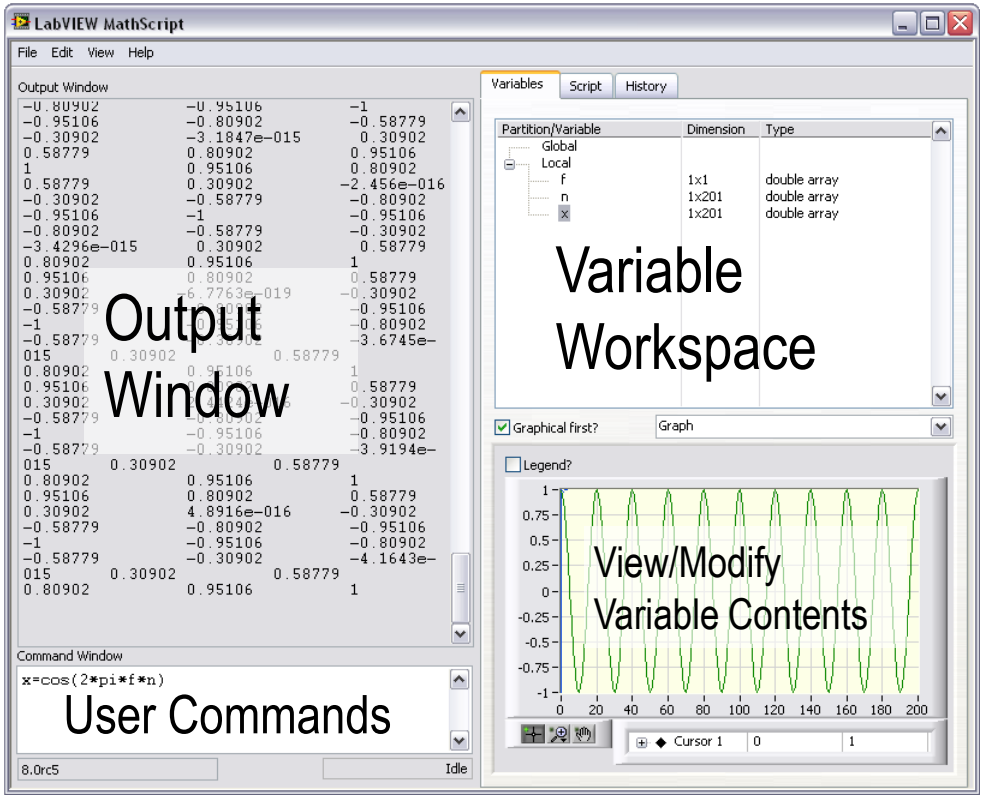


Prototype your equations in the interactive MathScript Window.

The Interactive MathScript Window

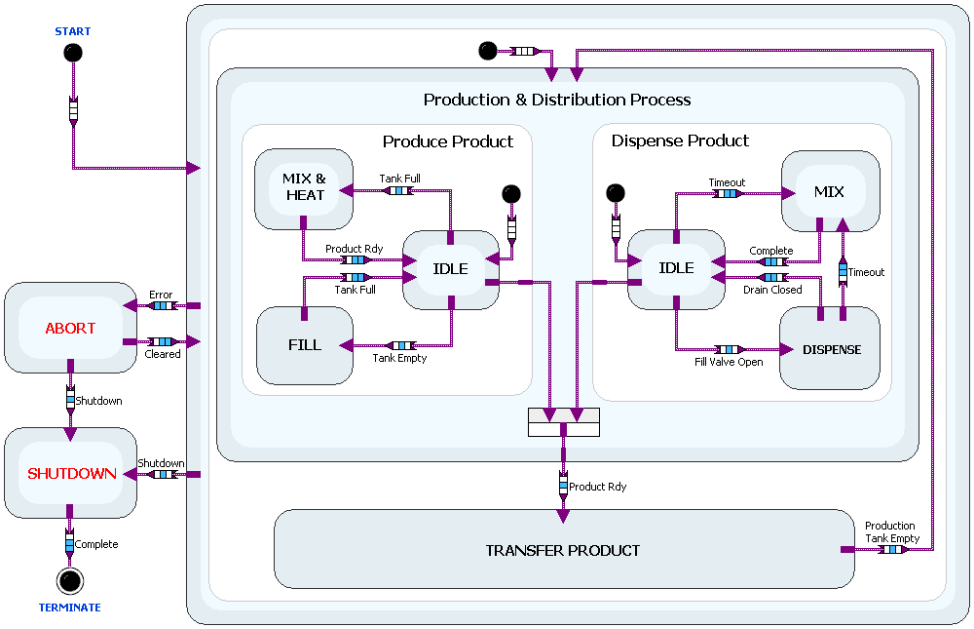
- Rapidly develop and test algorithms
- Share Scripts and Variables with the Node
- View /Modify Variable content in 1D, 2D, and 3D



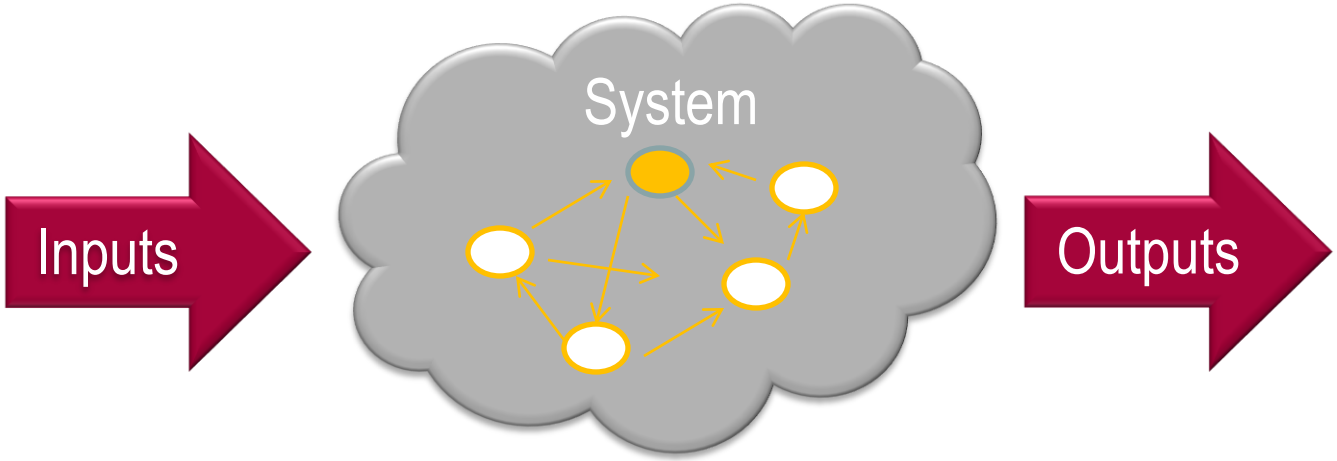


(LabVIEW»Tools»MathScript Window)

Developing Applications with the NI LabVIEW Statechart Module



What are Statecharts?

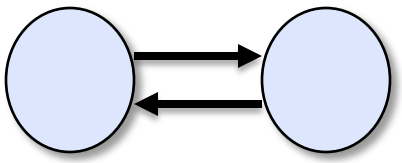


Statecharts are visual representations of reactive (event-based) systems.

Differences between Statecharts and FSMs

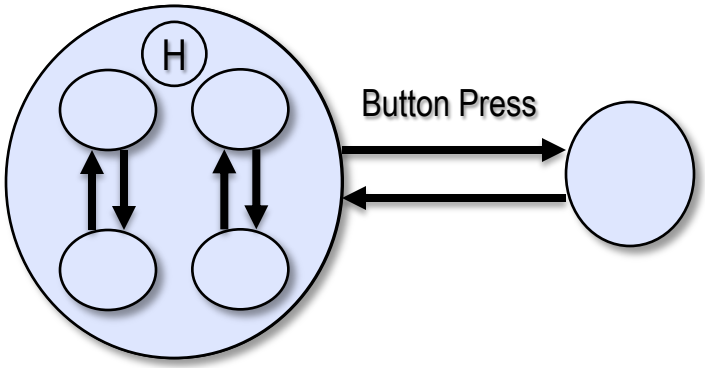
Both contain the same basic concepts:

- States
- Transitions



Statechart adds additional concepts:

- Hierarchy
- Concurrency
- Event-based paradigm
- Pseudostates & Connectors



Based on the UML statechart diagram specification

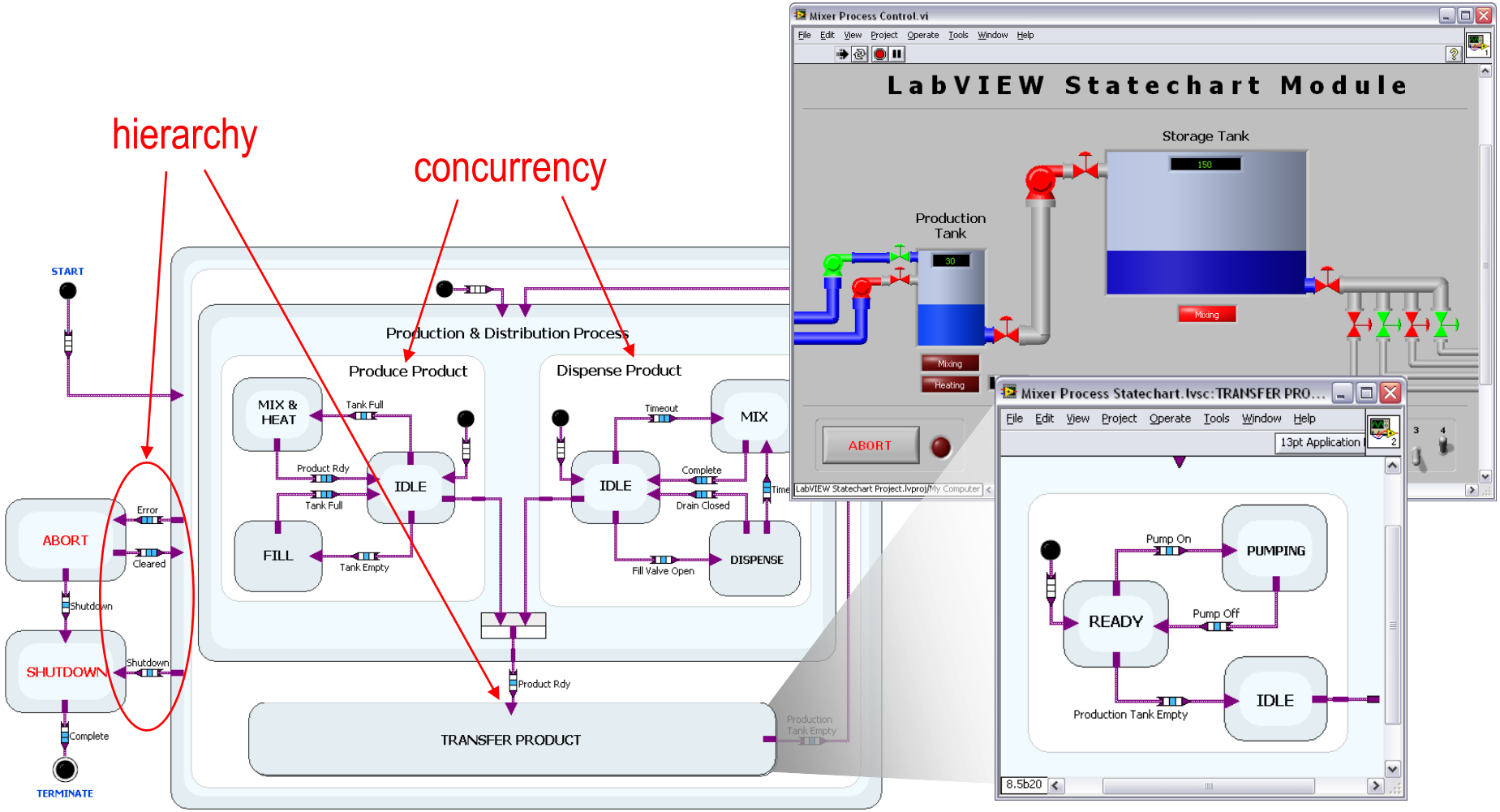
Reactive Systems

- Communication systems
- Digital protocols
- Control applications
  - Sequential logic
  - Batch processing
  - Event response
  - Non-linear control
- User-interface implementation
- System modeling for virtual prototyping (simulation)

Statechart Benefits

- Abstraction
  - Simple semantics to represent complex systems
  - System-level view
  - Self-documenting

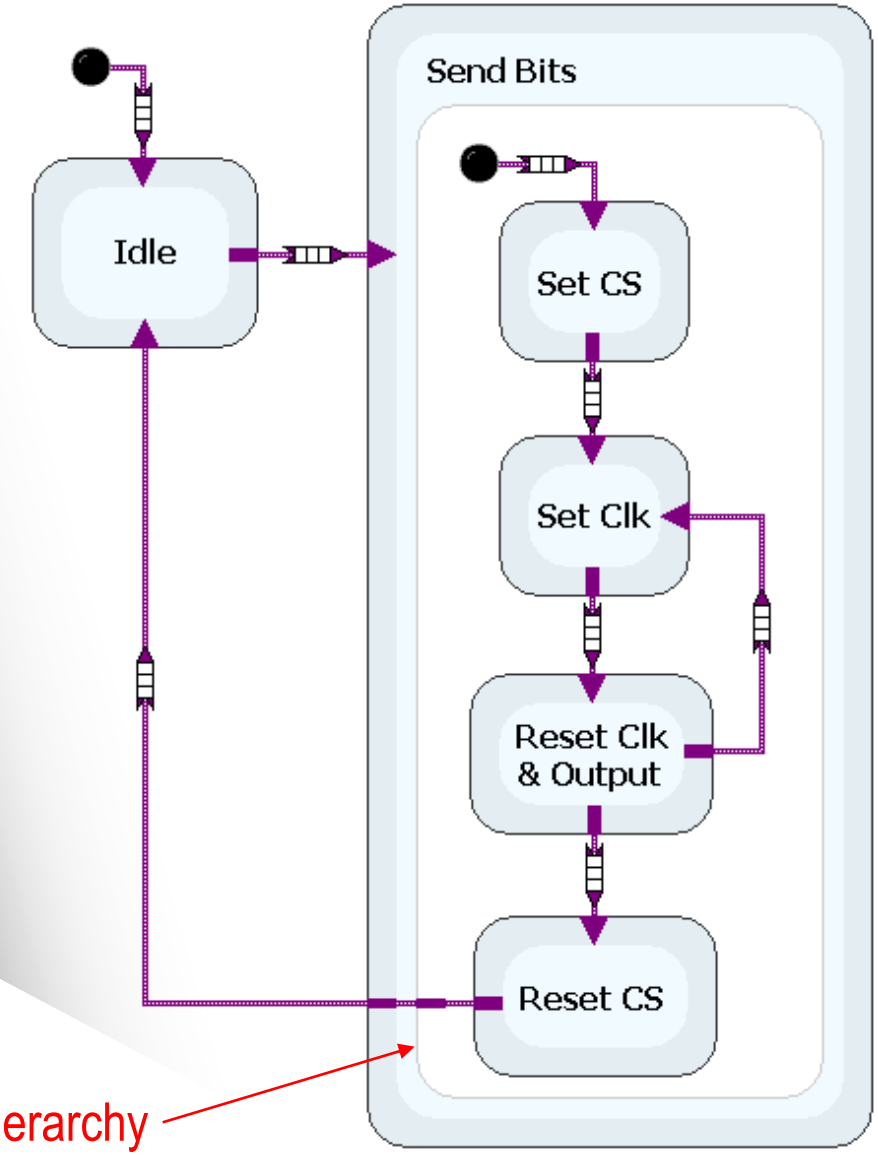
Machine & Process Control



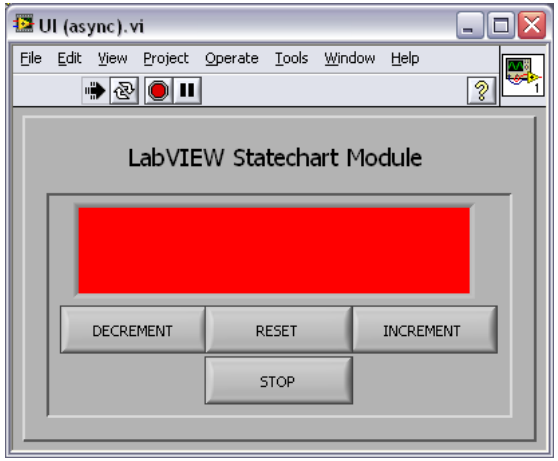
FPGA Logic

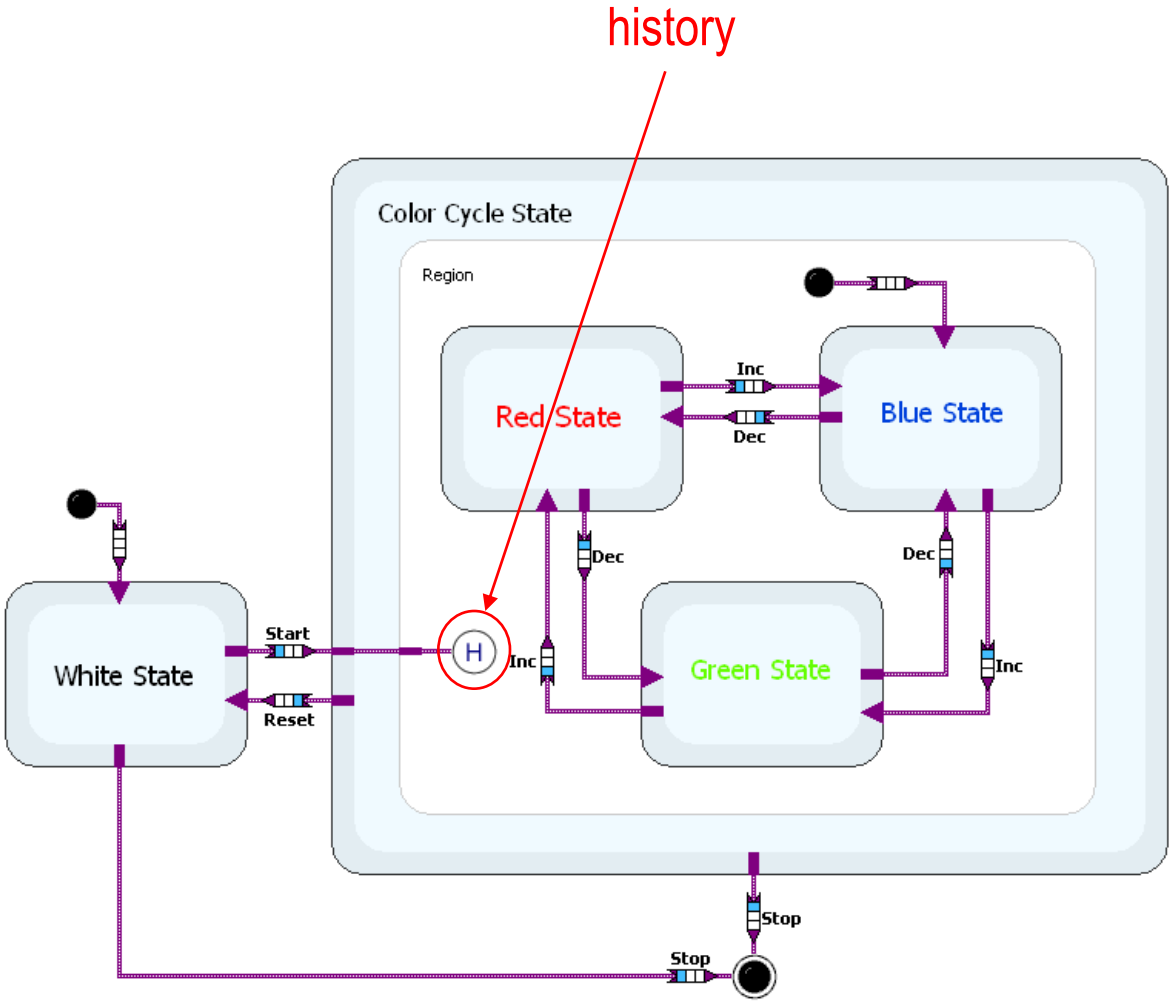

PXI


XILINX
XC4028EX
HQ240CMM9709
A42495A
3C


Send Bits
Idle
Set CS
Set Clk
Reset Clk & Output
Reset CS
hierarchy

User Interfaces





Statechart Benefits

- Abstraction
  - Simple semantics to represent complex systems
  - System-level view
  - Self-documenting
- Scalability
  - Easily extend applications
  - Open software platform
- Automatic Code Generation
  - LabVIEW Embedded Technology

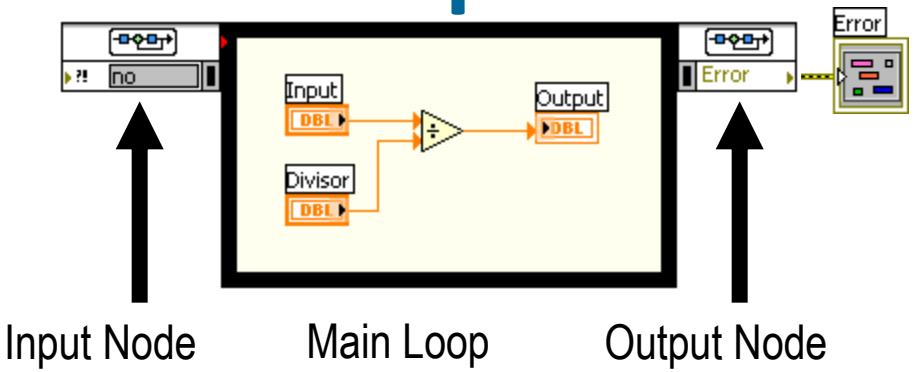
LabVIEW Simulation Module

- Develop dynamic systems such as motor controllers and hydraulic simulators with LabVIEW
- Implement your dynamic systems with real-time I/O using built-in LabVIEW data acquisition functions
- Simulate linear, nonlinear, and discrete systems with a wide array of solvers
- Deploy dynamic systems to real-time hardware with the NI LabVIEW Real-Time Module
- Translate models from The MathWorks, Inc. Simulink® into LabVIEW with built-in utility

The Design Process

1. **Modeling** – Identify a mathematical representation of the plant
2. **Control Design** – Choose a control method and design a controller
3. **Simulation** – Employ a point-by-point approach to simulate the system timing with a solver
4. **Tuning and Verification** – Introduce real-world nonlinearities, tune, and verify the control algorithm
5. **Deployment** – Implement the finalized control system

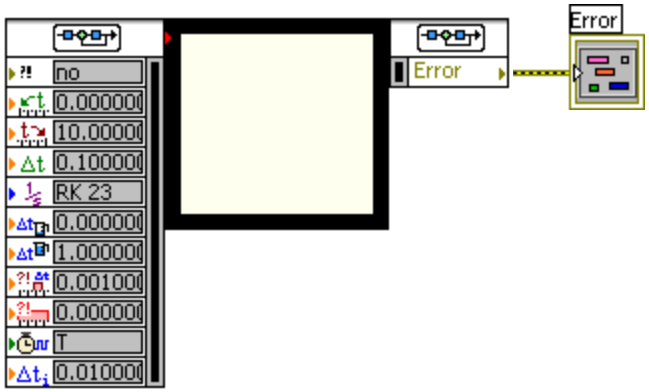
The Simulation Loop



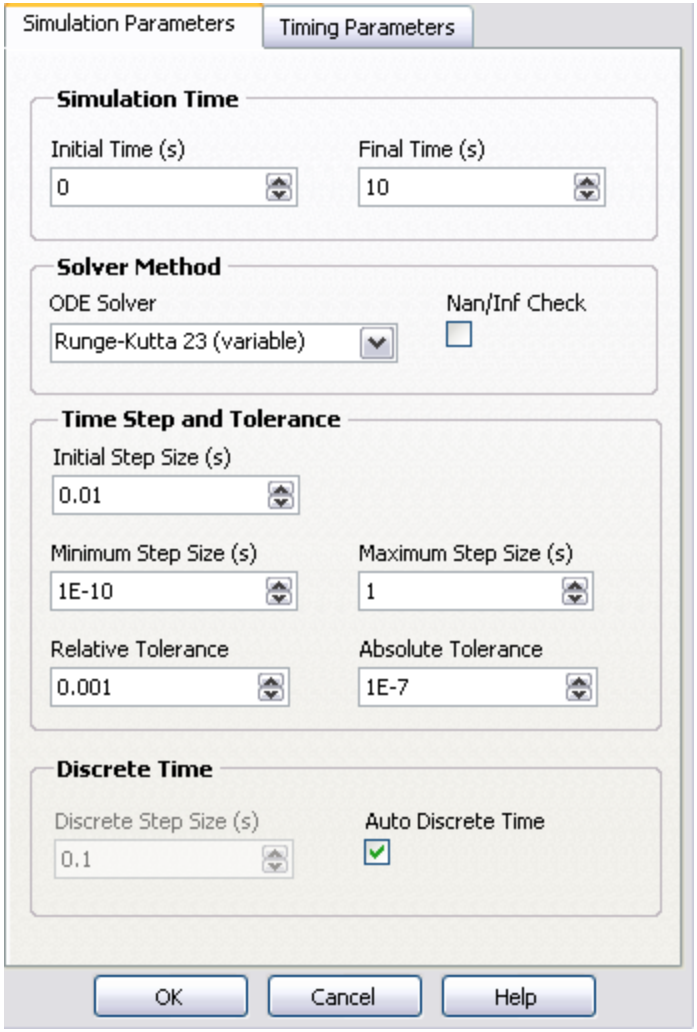
- Built in Differential Equation Solver allows continuous-time system
- Similar to a While Loop with a predefined time period
- Installed with Simulation Module
- Double-click Input Node to configure simulation parameters
- Create an indicator on the Output Node to display Simulation errors

Simulation Loop Parameters

- Drag left node to show current parameters and provide inputs for run-time simulation configuration

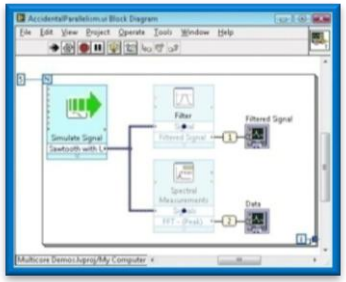


- Double-click Input Node to configure simulation parameters

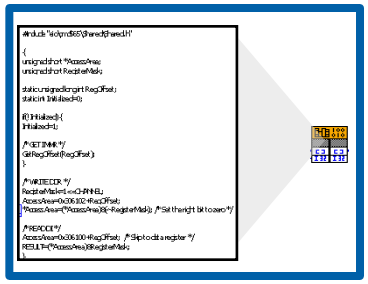


High-Level Development Tools

Data Flow



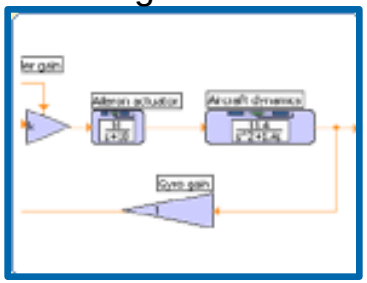
C Code



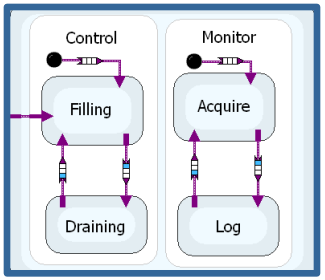
Textual Math

```
c = 0.285 + 0.013i;
[X Y] = meshgrid(x, y);
z = X + i*Y;
for k=1:30
    z = z.^2 + c;
end
```

Modeling



Statechart



NATIONAL INSTRUMENTS

LabVIEW™

Graphical System Design Platform

Desktop Platform

Linux®

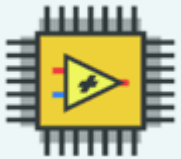
Macintosh

Windows

Embedded Platform

Real-Time

FPGA



Micro

Targets and Deployment

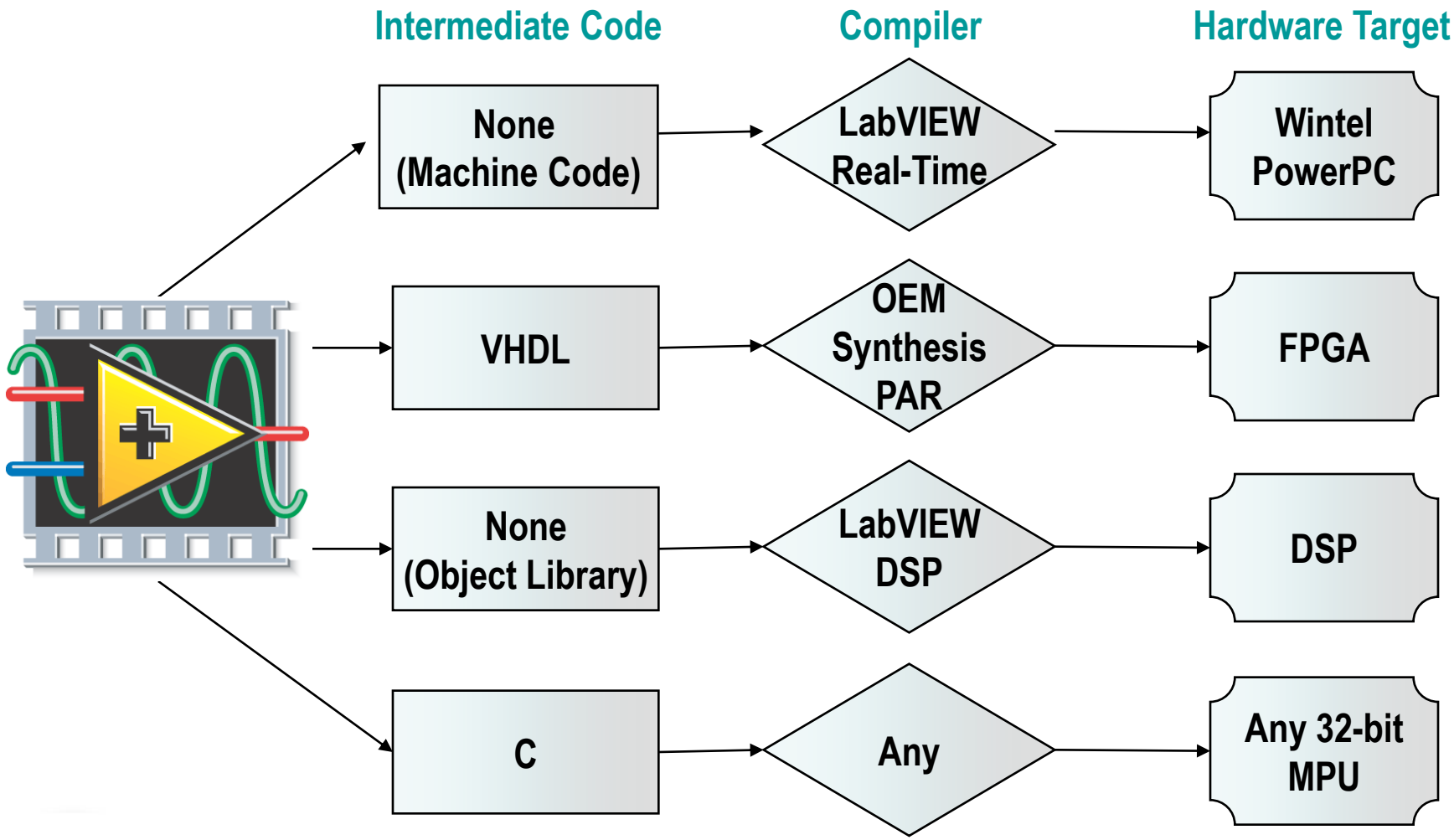
LabVIEW Real-time

LabVIEW FPGA

LabVIEW Microprocessor SDK

LabVIEW PDA and related

Evolution of LabVIEW Backend Technologies

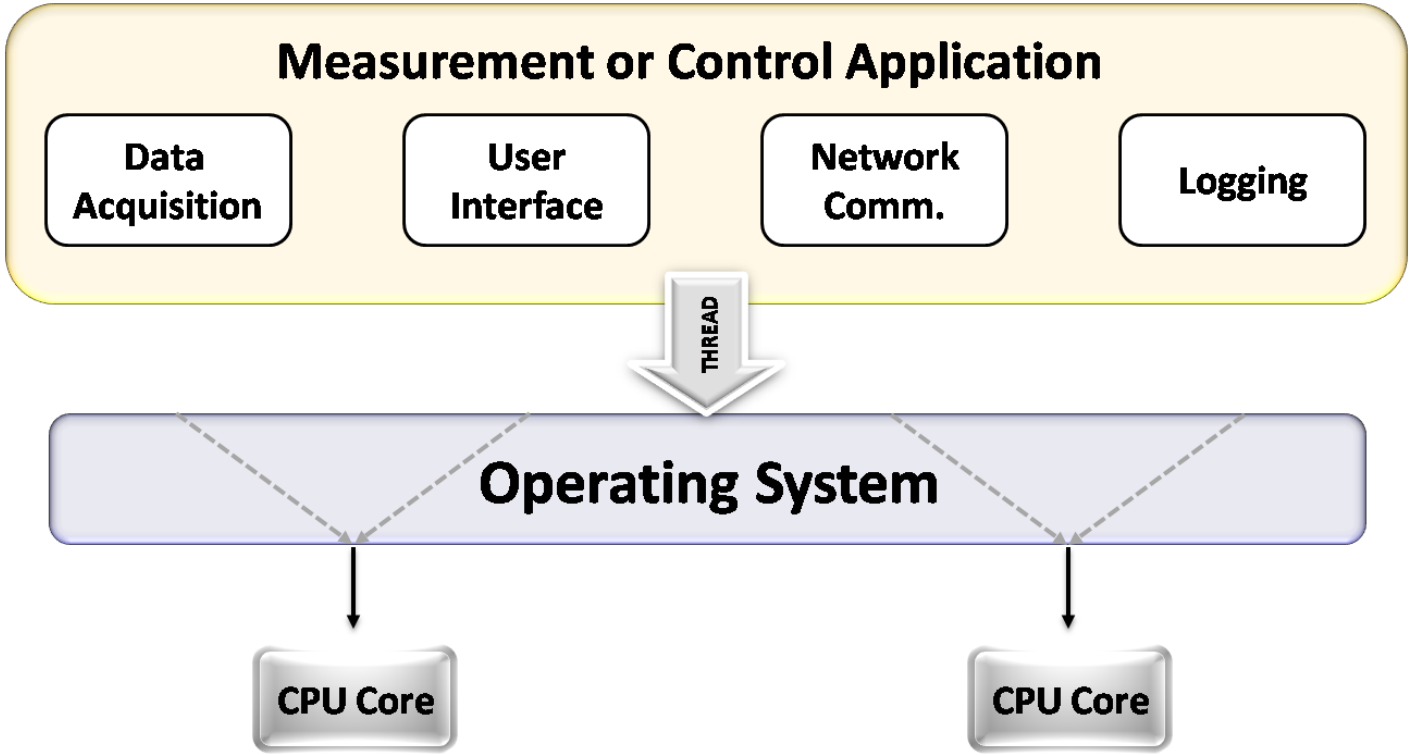


LabVIEW for Parallel Programming

- Overview of LabVIEW Multithreading
- Parallel Programming Techniques
- Real-Time Considerations
- Resources

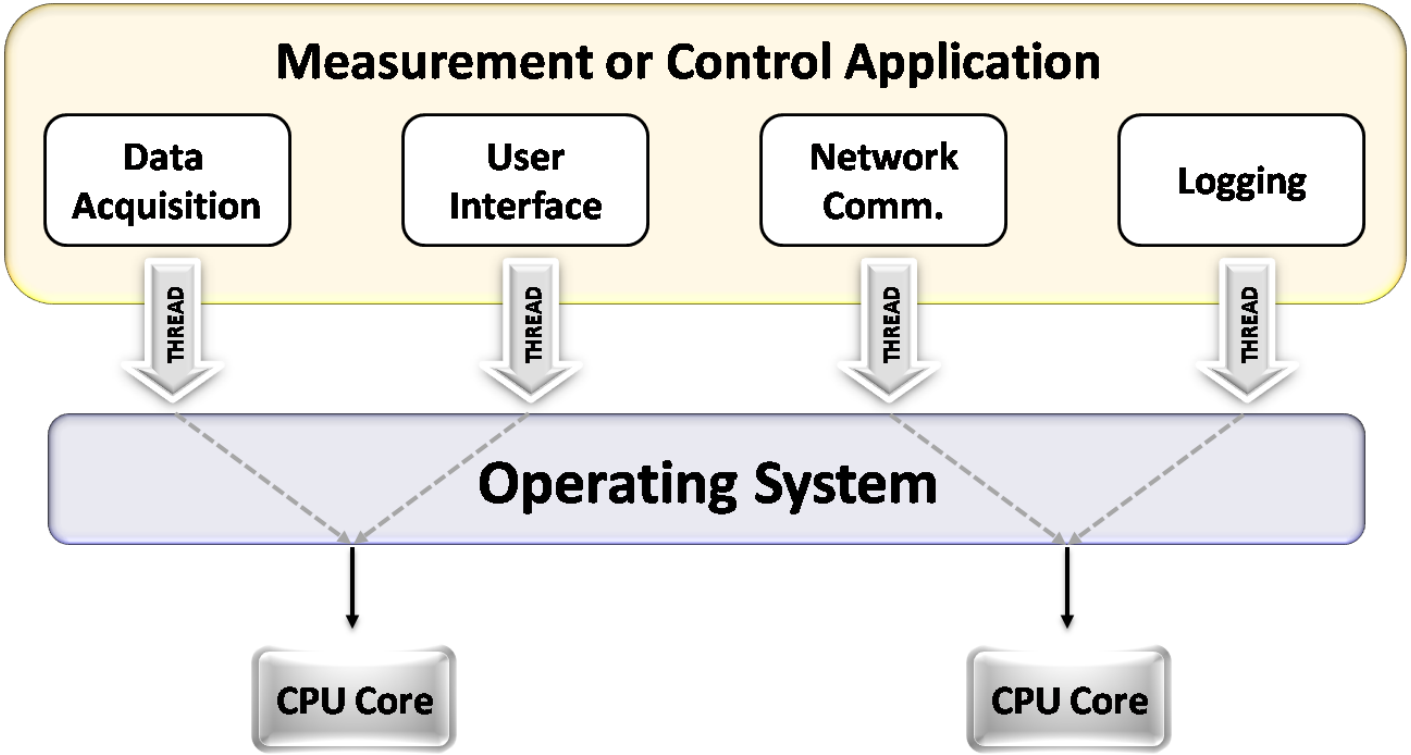
Impact on Engineers and Scientists

Engineering and scientific applications are typically run on dedicated systems (i.e. little multitasking).



Creating Multithreaded Applications

Engineers and scientists **must** use threads to benefit from multicore processors.



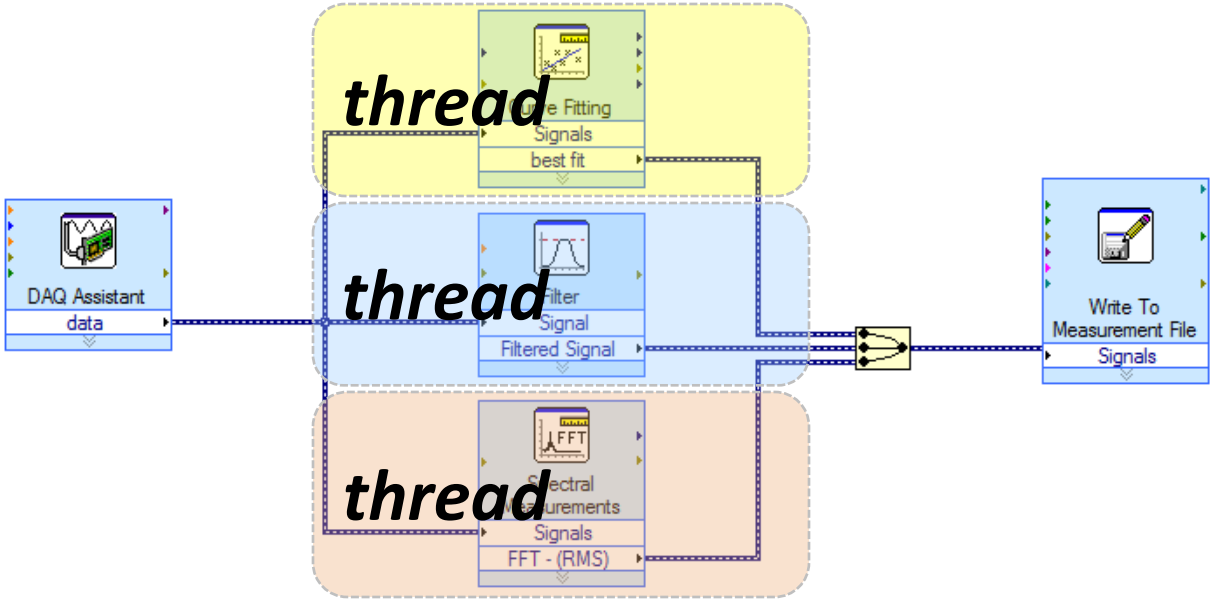
Multithreading Programs in LabVIEW

- Automatic threading
  - LabVIEW clumping algorithm automatically assigns code to threads based on parallelism
  - Most existing programs will run faster on a Multicore system **with no alteration**

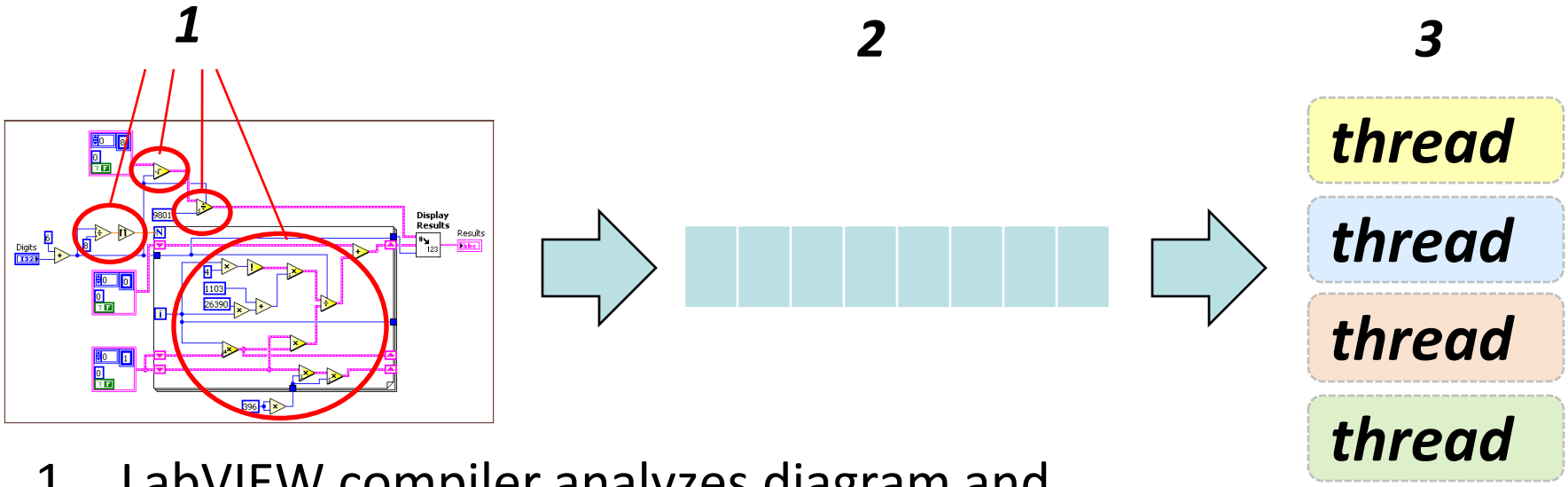
- Manual threading
  - Force section of code to execute in a single thread

Automatic Multithreading

- LabVIEW divides a program into multiple threads (originally introduced in 1998 with LabVIEW 5.0)
- Oversimplification shown below; parallel code paths execute in separate threads to run on parallel hardware



LabVIEW Execution System



# of threads scales based on # of CPUs

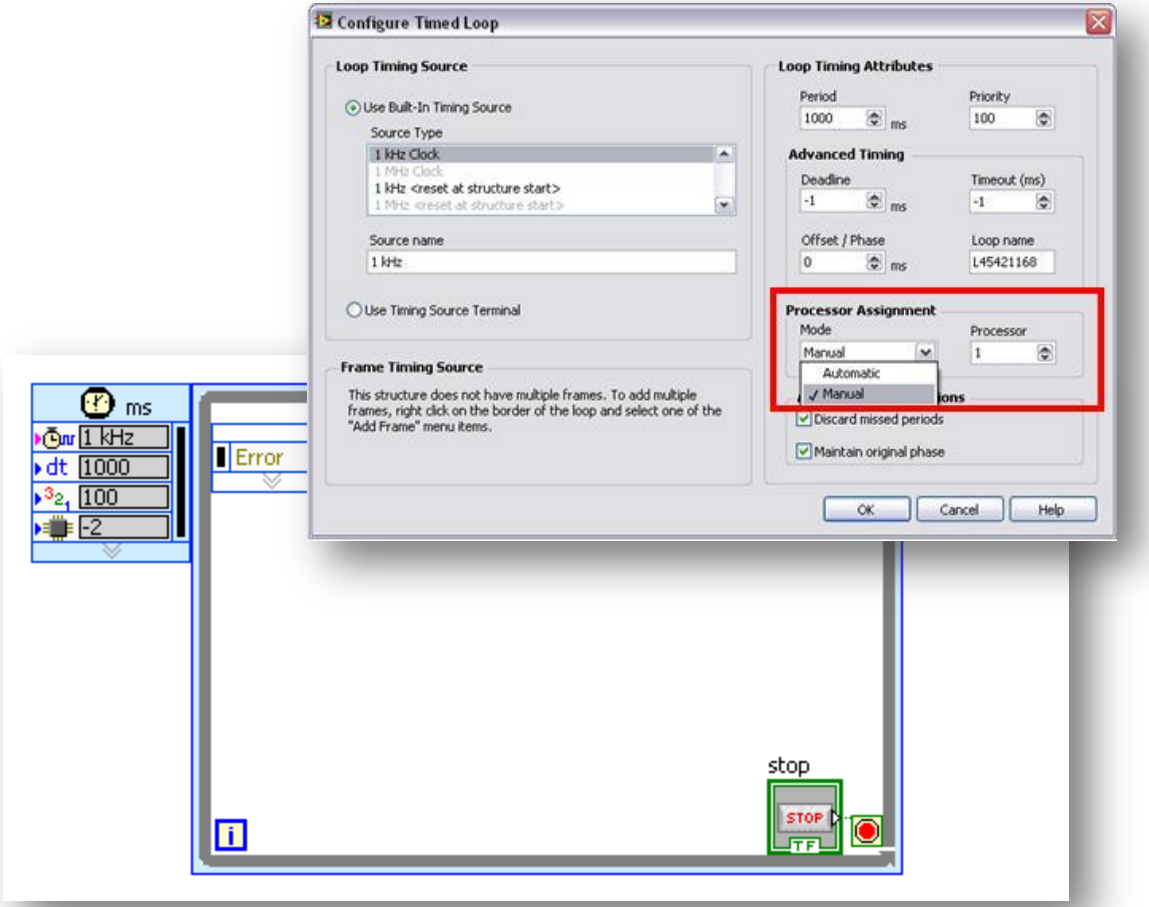
1. LabVIEW compiler analyzes diagram and assigns code pieces to “clumps”
2. Information about which pieces of code can run simultaneously are stored in a run queue
3. If block diagram contains enough parallelism, it will simultaneously execute in all system threads

Multithreaded Software Stack Support

Software Stack		
Development tool	Support provided on the operating system of choice; tool facilitates correct threading and optimization	✓ Example: Multithreaded nature of LabVIEW and structures that provide optimization
Libraries	Thread-safe, re-entrant libraries	✓ Example: BLAS libraries
Device drivers	Drivers designed for optimal multithreaded performance	✓ Example: NI-DAQmx driver software
Operating system	Operating system supports multithreading and multitasking and can load balance tasks	✓ Example: Support for Windows, Mac OS, Linux® OS, and real-time operating systems

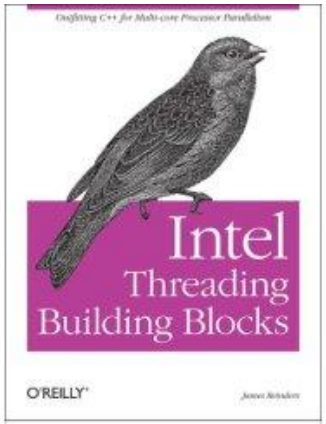
Manual Threading with Timed Structures

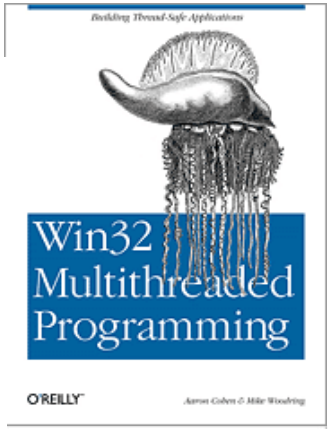
- Code within timed structure executes in a single thread
- Threads can be assigned a relative priority
- Set processor affinity

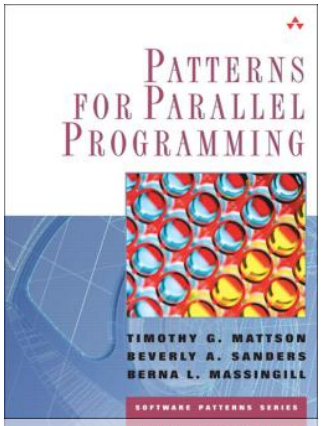


Parallel Programming Techniques to Improve Performance on Multicore Systems

- Task Parallelism
- Data Parallelism
- Pipelining





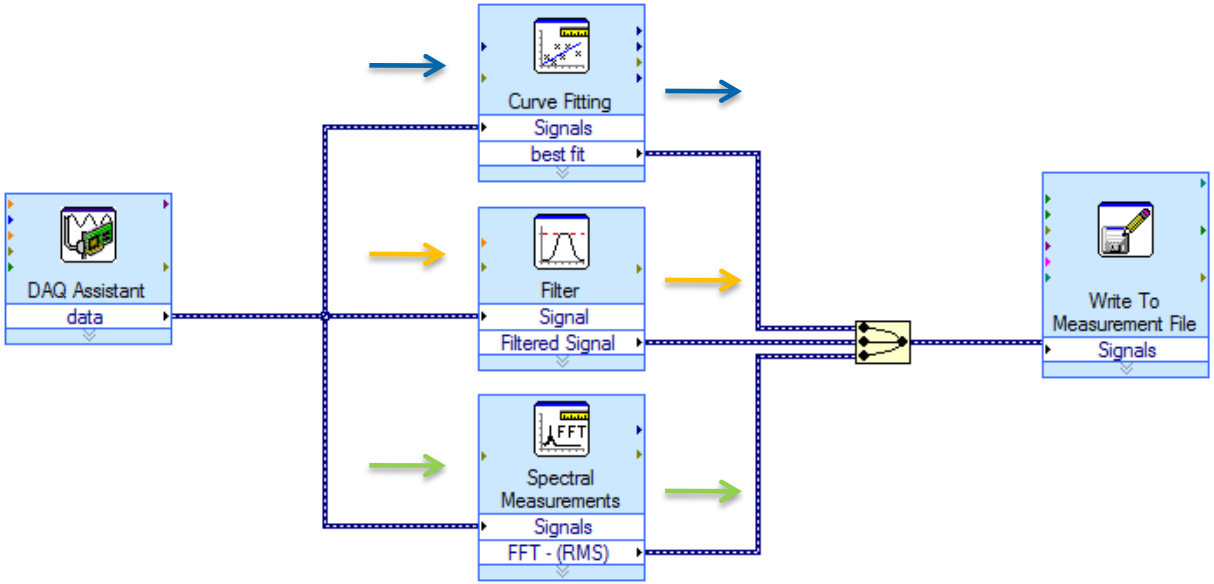


Task Parallelism

1) Look for tasks that can be run in parallel
2) Architect code to reflect this parallelism
   - Eliminate data dependencies
   - LabVIEW automatically identifies parallel code and can split into multiple threads!

Task Parallelism

- Multiple tasks, same data
- Multiple data-independent tasks



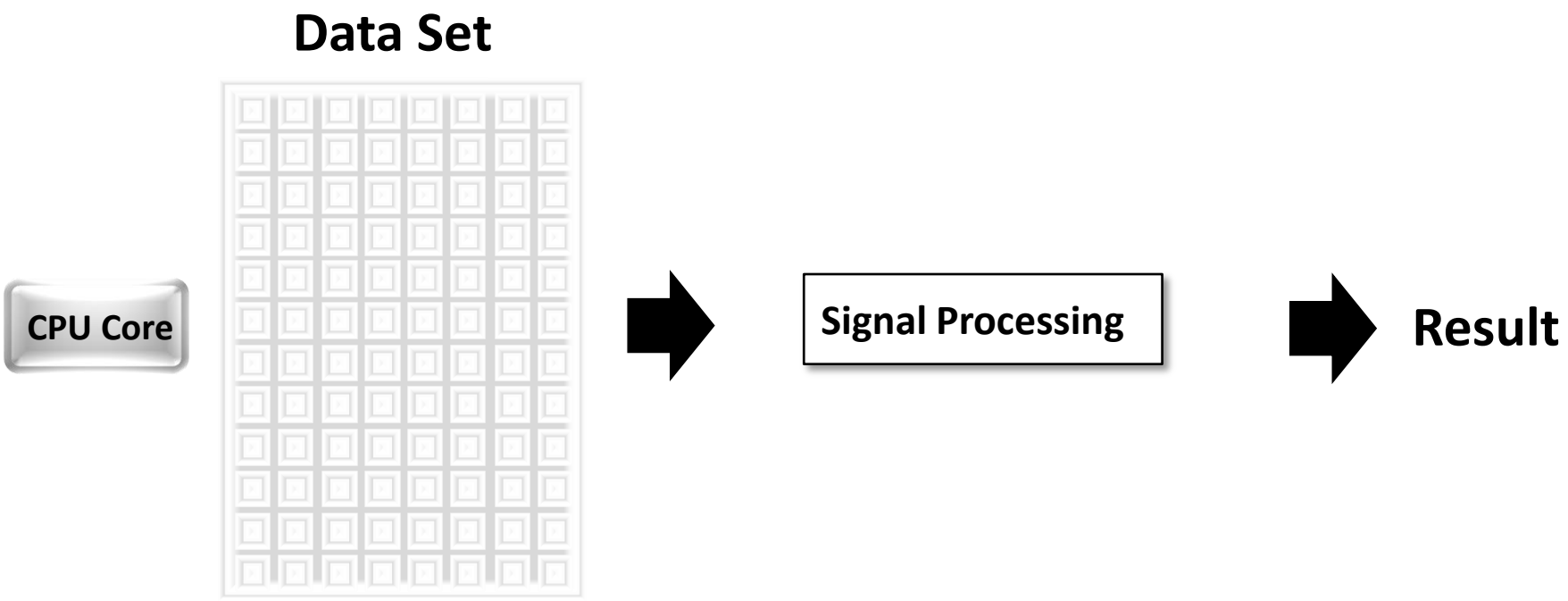
Task Parallelism Demo

Data Parallelism

1) Look for large data sets that can be processed in two or more “chunks” independently

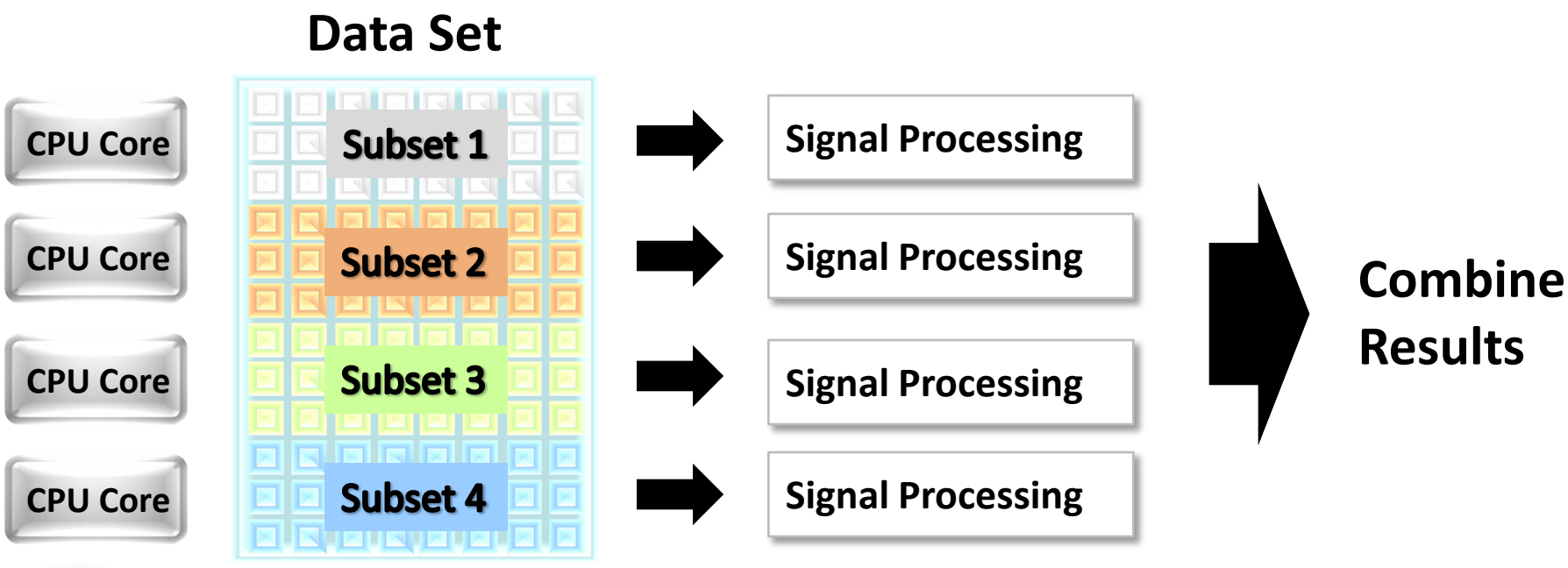
2) Architect code:
   - Split the data apart
   - Process the data in parallel
   - Combine the individual results into one overall result

Data Parallelism



Data Parallelism

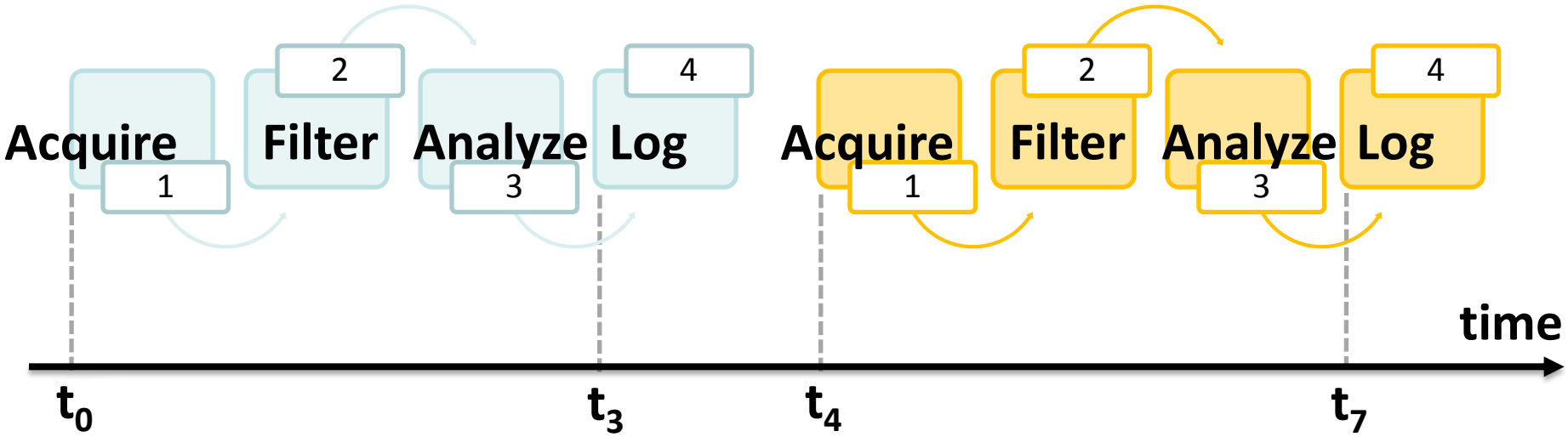
You can speed up processor-intensive operations on large data sets on multicore systems.



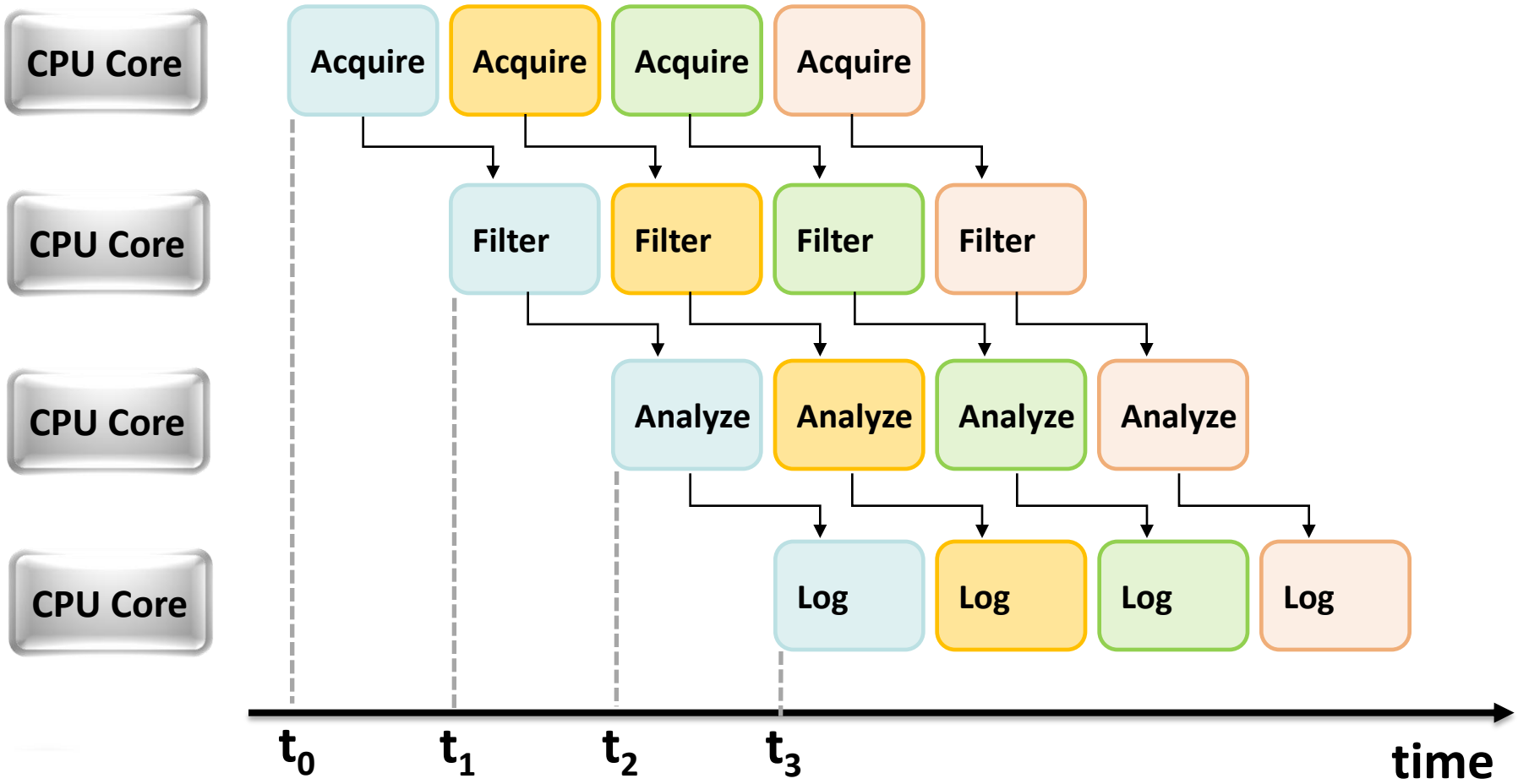
Data Parallelism Demo

Pipelining Strategy

- Many applications involve sequential, multistep algorithms that are executed over and over again
- Applying pipelining can increase performance

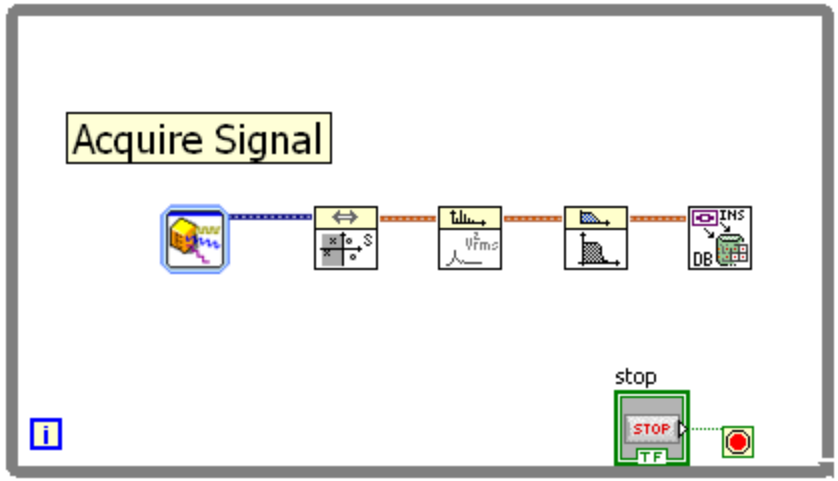


Pipelining Strategy

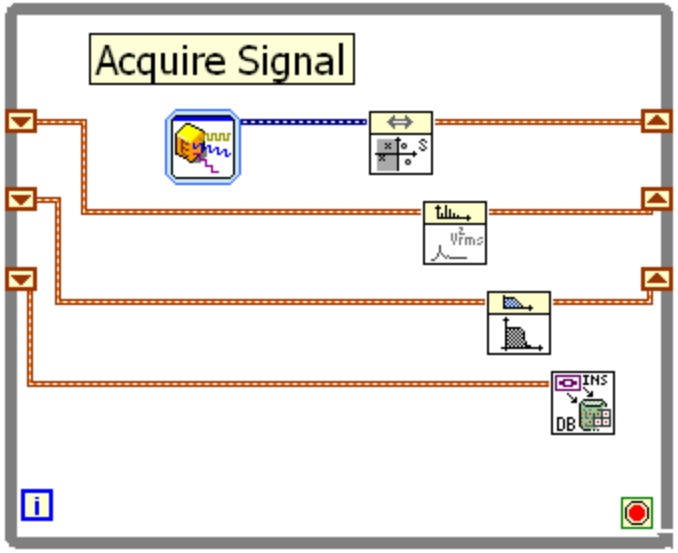


Pipelining in LabVIEW

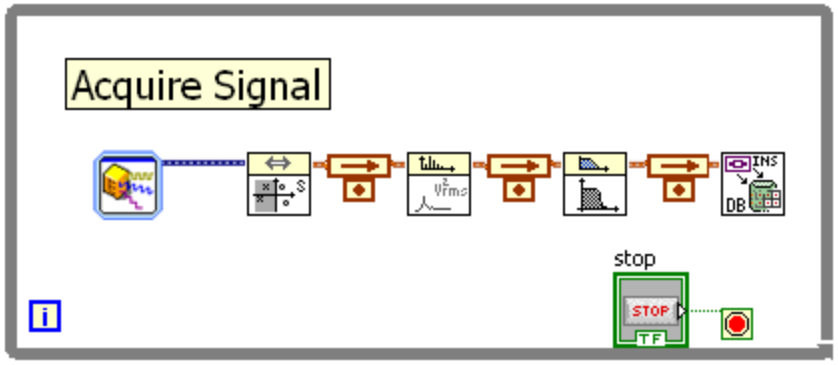
Sequential



Pipelined



or



Note: Queues may also be used to pipeline data between different loops

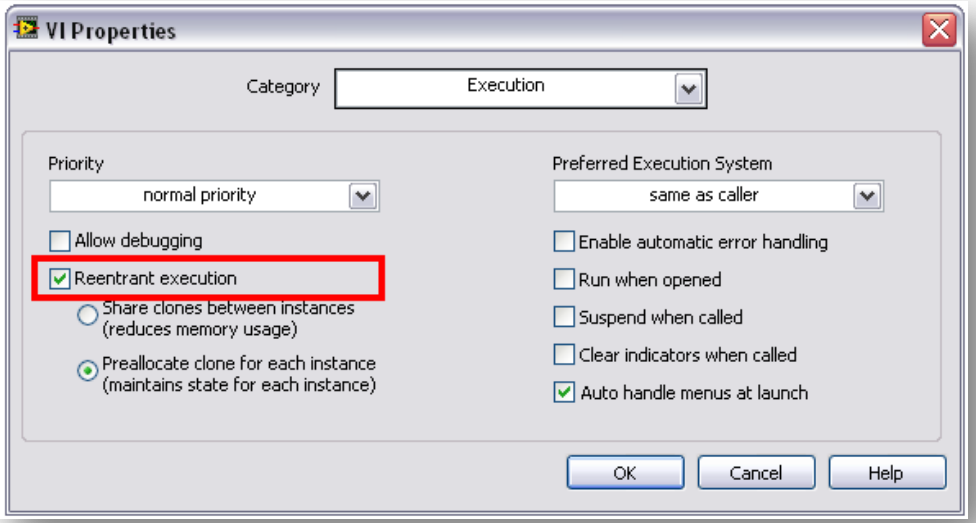
Pipelining Demo

Multicore Challenges and Debugging

- Reentrancy and execution highlighting
- Thread synchronization
- Execution tracing
- Performance counters
- Data transfer considerations

Reentrancy

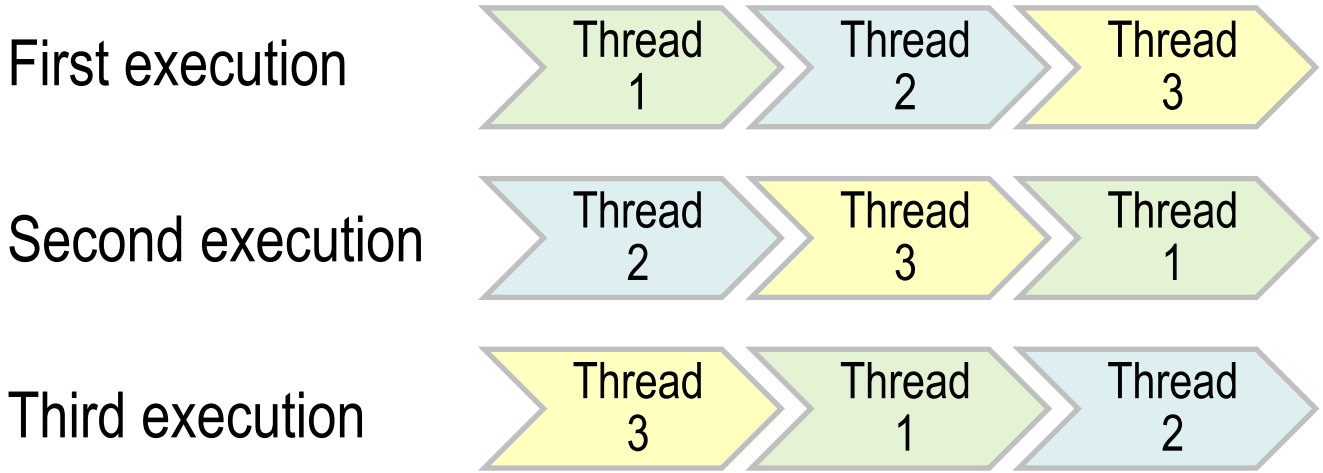
- All VIs in LabVIEW can bet set to be reentrant
- Allows for each subVI to use separate memory space



All subVIs that will be executed multiple times in parallel need to be set as reentrant

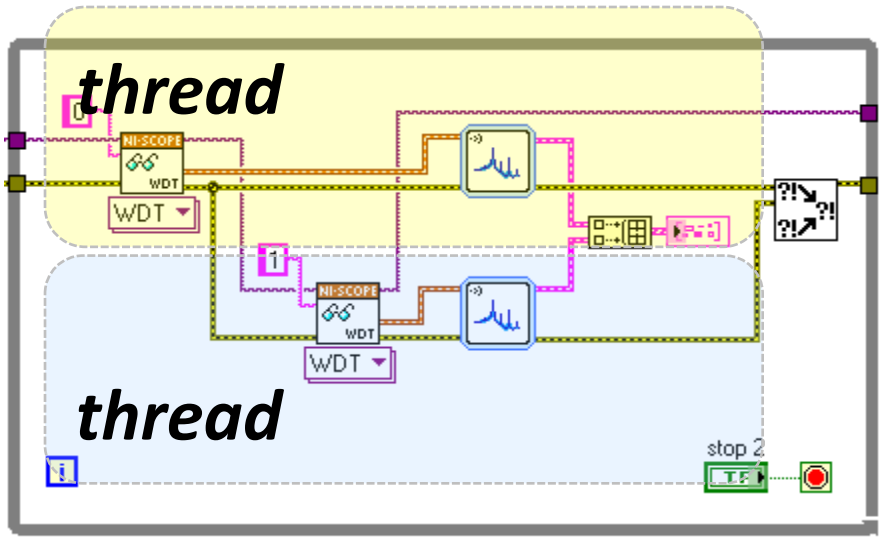
Thread Synchronization

- No guarantee that an OS will schedule threads in the correct sequence without synchronization primitives
- Order of events may change at each execution due to the way the threads are scheduled



Code Synchronization with Dataflow

- Dataflow paradigm <u>ensures</u> synchronization

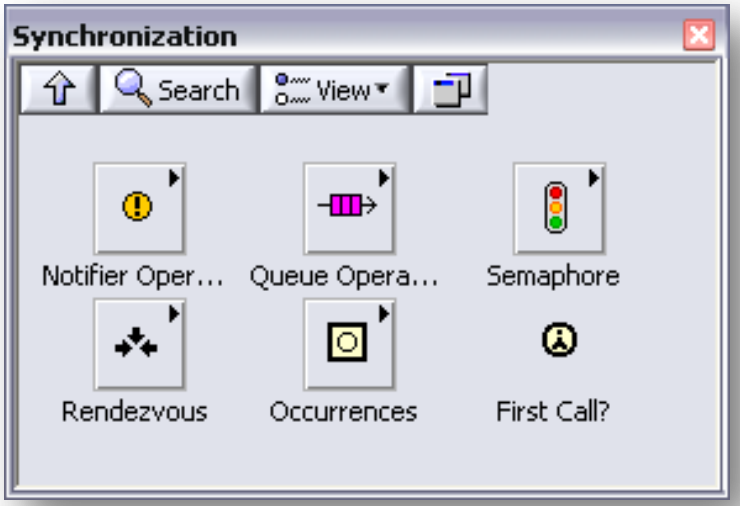


Parallel code paths are synchronized and order of execution is determined by LabVIEW wires

Dataflow is a key enabler for Multicore programming

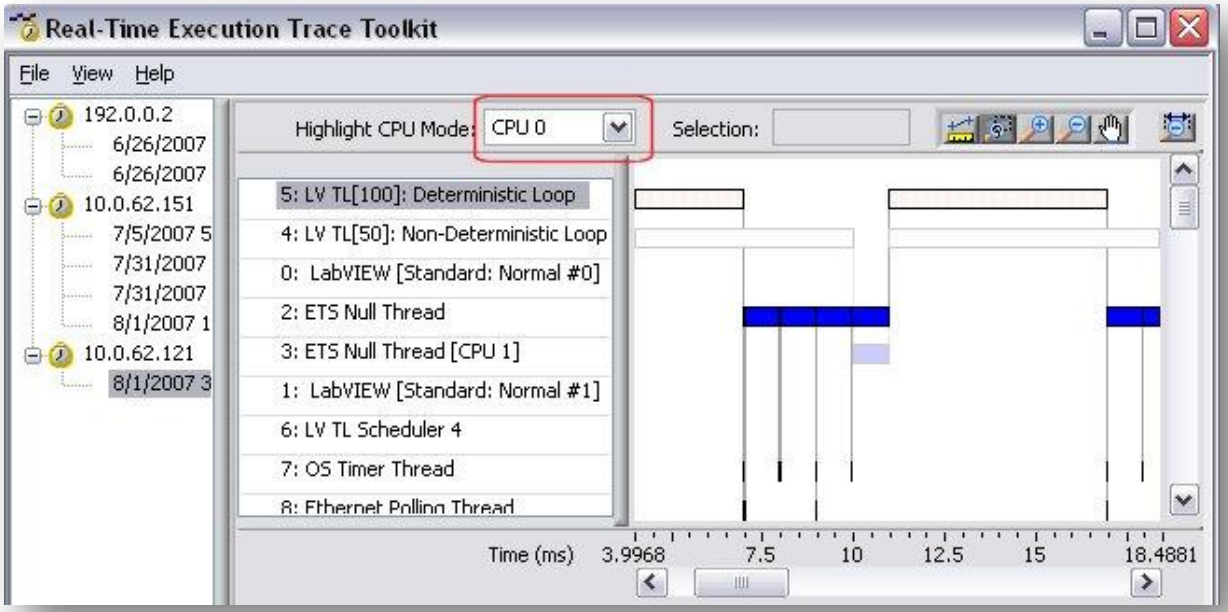
Synchronization in LabVIEW

- When low-level synchronization is required, use synchronization mechanisms including:
  - Queues
  - Notifiers
  - Semaphores
  - Rendezvous
  - Occurrences



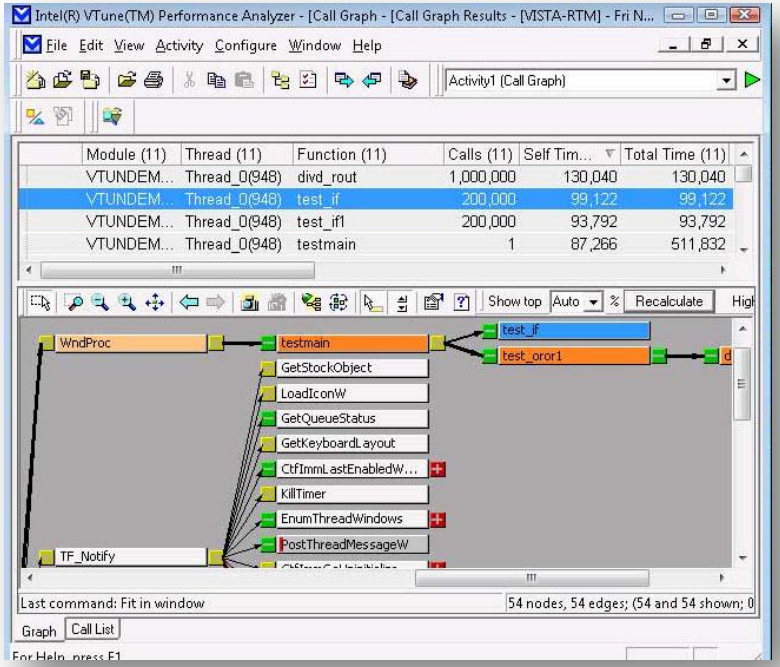
Execution Tracing

- On real-time systems, trace debugging can show thread activity at the OS level
- Thread activity on each core is displayed by selecting a particular CPU



Performance Counters

- Performance counters provide detailed system information (CPU usage, memory usage, and cache hits/misses)
- LabVIEW can call into Windows performance counters
- Example utilities:
  - Windows Perfmon
  - Intel's VTune

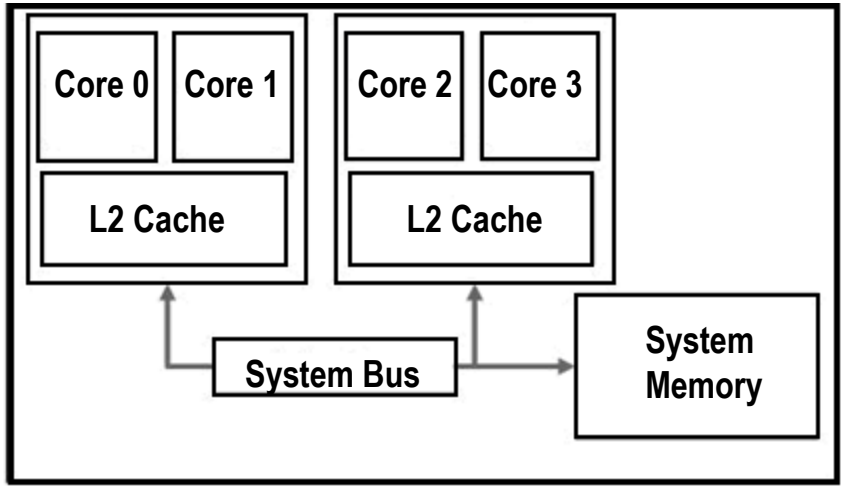


Data Transfer Considerations

- Carefully consider system memory architecture when programming for Multicore
- Avoid transferring overly large data sets between cores (relative to cache size)
- Very small memory transfers can cause repeated cache coherency updates

Physical Processor Layout

- Distance between processors and quality of processor connections can have a large effect
- Transferring data over system bus is much slower than accessing a shared cache

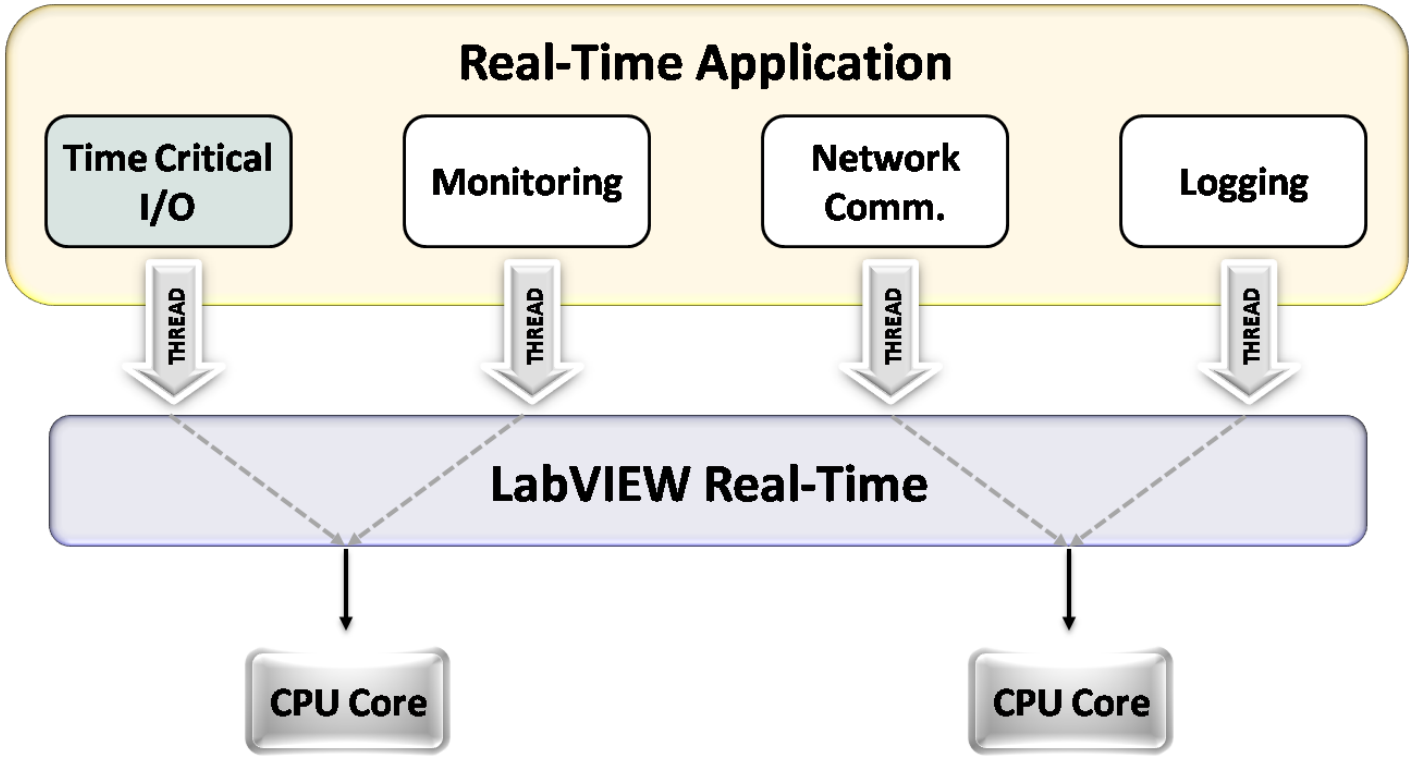


<u>Shared Cache Example:</u>
Dual-Core, Dual Processor System

Source: Tian and Shih, Software Techniques for Shared-Cache Multi-Core Systems, Intel Software Network

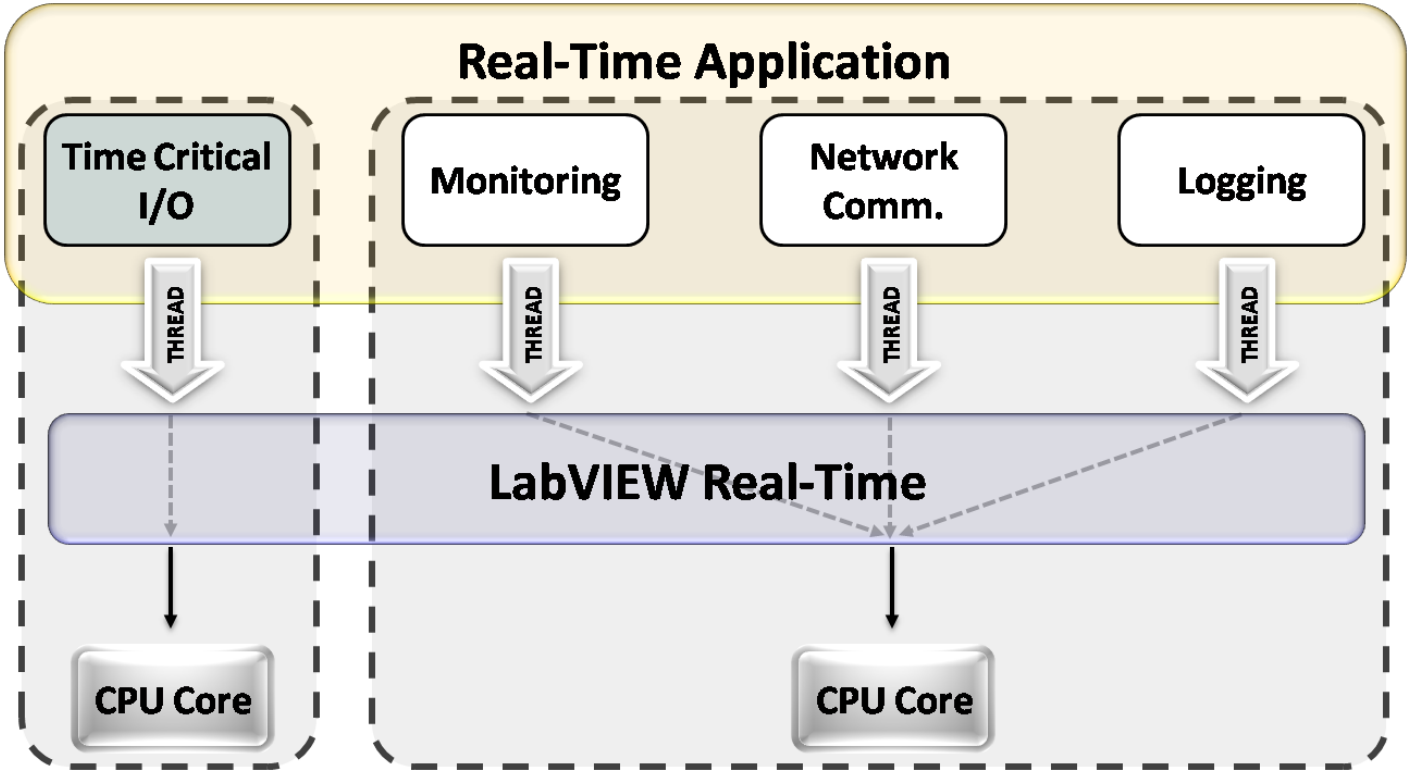
Deterministic Real-Time Systems

LabVIEW 8.5 adds Symmetric Multiprocessing (SMP) for real-time systems.

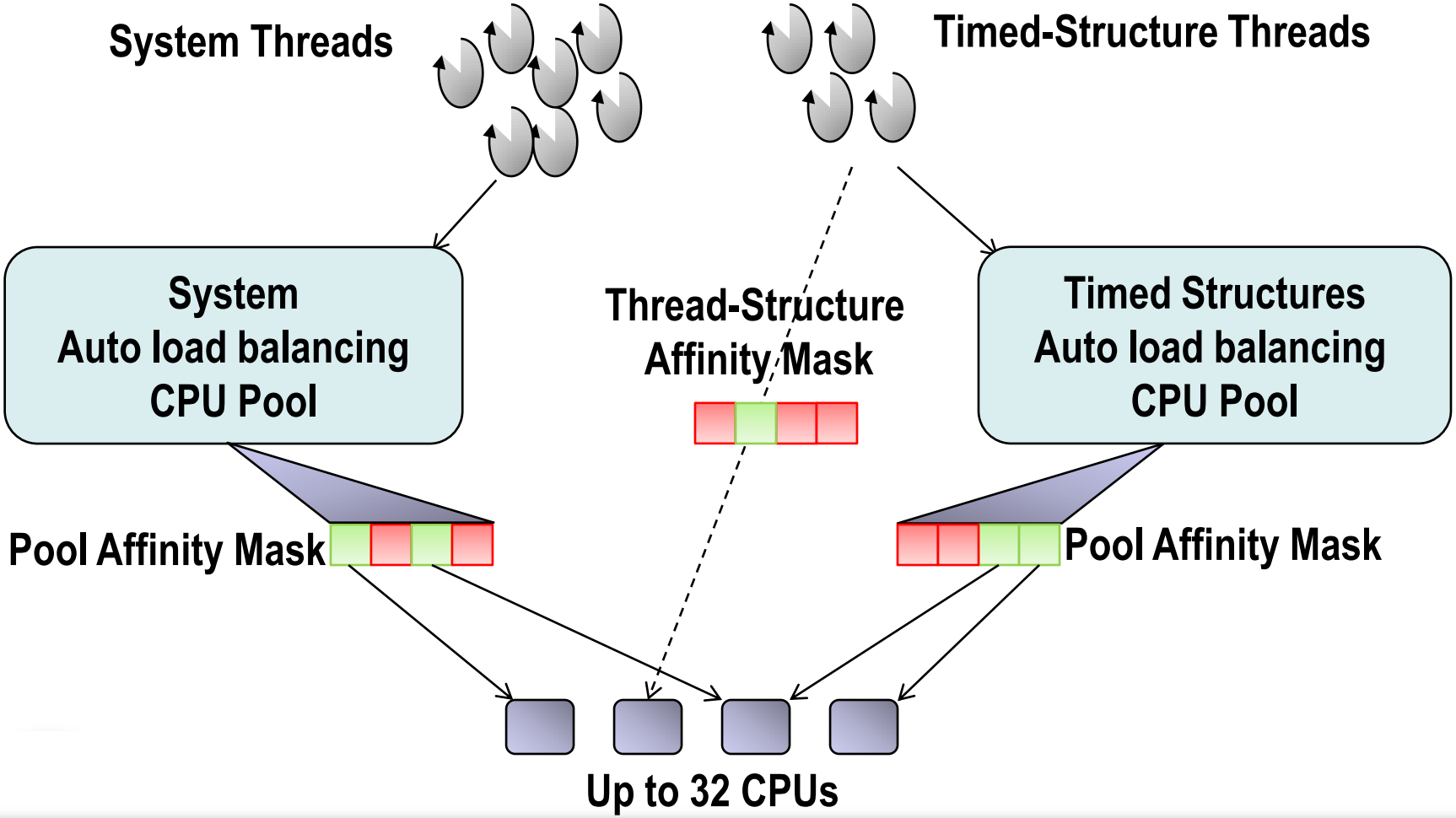


Assigning Tasks to Specific Cores

In LabVIEW 8.5, users can reserve a core and then assign time critical code to run on it

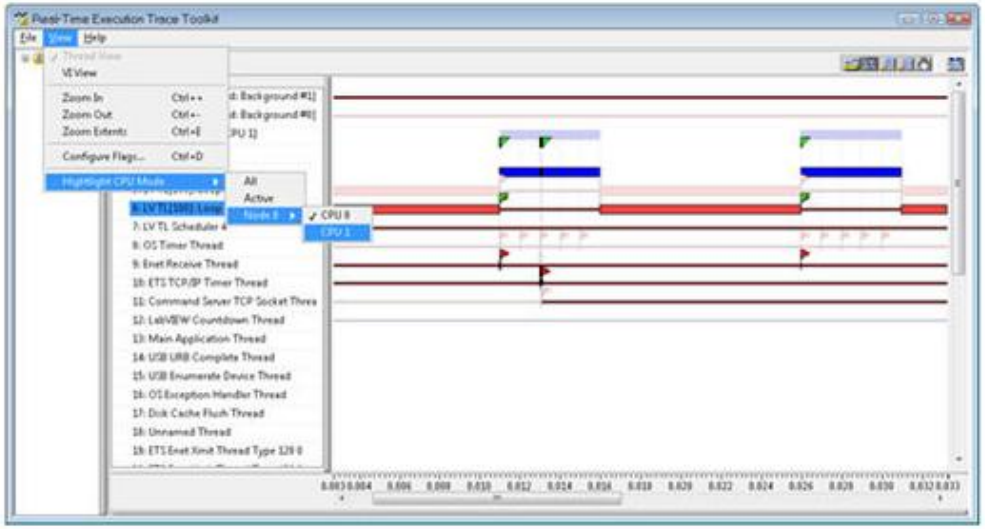


Affinity, pools, threads, CPUs, etc.



Execution Trace Toolkit

- LabVIEW Real-Time Only
- Thread view
- VI view (function view)
- Multicore support
- Debugging flags (memory manager collisions, mutex collisions, priority inheritance, ISRs, etc.)
- Trace Activity Sorting



Resources

www.ni.com/multicore

Multicore Programming Resources

Questions? Get real-time assistance now!

Introducing LabVIEW 8.5

Get the Most from Your Multicore Processor

View the webcast >>

Multicore processors present new software challenges that must be overcome to fully take advantage of processing capabilities in test, control, and embedded design applications. Explore the following resources to learn how engineers and scientists can use graphical programming to implement parallel programming strategies and harness the power of multicore processors.

Multicore Programming Fundamentals

View the Multicore Programming Whitepaper Series

Browse the library of whitepapers to learn about multicore programming strategies, key concepts, and performance benchmarks.

Develop High-Performance Real-Time Systems with Multicore Technology

Technical Resources

- Overcoming Multicore Programming Challenges with LabVIEW
- Programming Strategies for Multicore Processing: Task Parallelism
- Will my LabVIEW program run faster when I upgrade to a multicore computer?