Kanad Basu

Outline

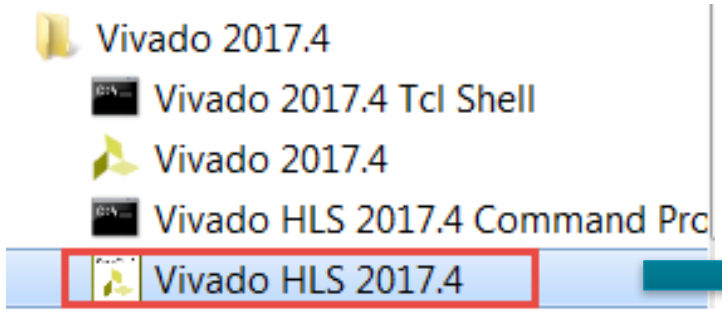
- *Invoking Vivado HLS*
- Project Creation using Vivado HLS
- Synthesis to IPXACT Flow
- Design Analysis
- Other Ways to use Vivado HLS
- Summary

Vivado HLS OS Support

- Vivado HLS is supported on both Linux and Windows
- Vivado HLS tool available under two licenses
  - HLS license
    - HLS license come with Vivado System Edition
    - Supports all 7 series devices including Zynq® All Programmable SoC
    - Does not support Virtex®-6 and earlier devices
      - Use older version of Vivado HLS for Virtex-6 and earlier

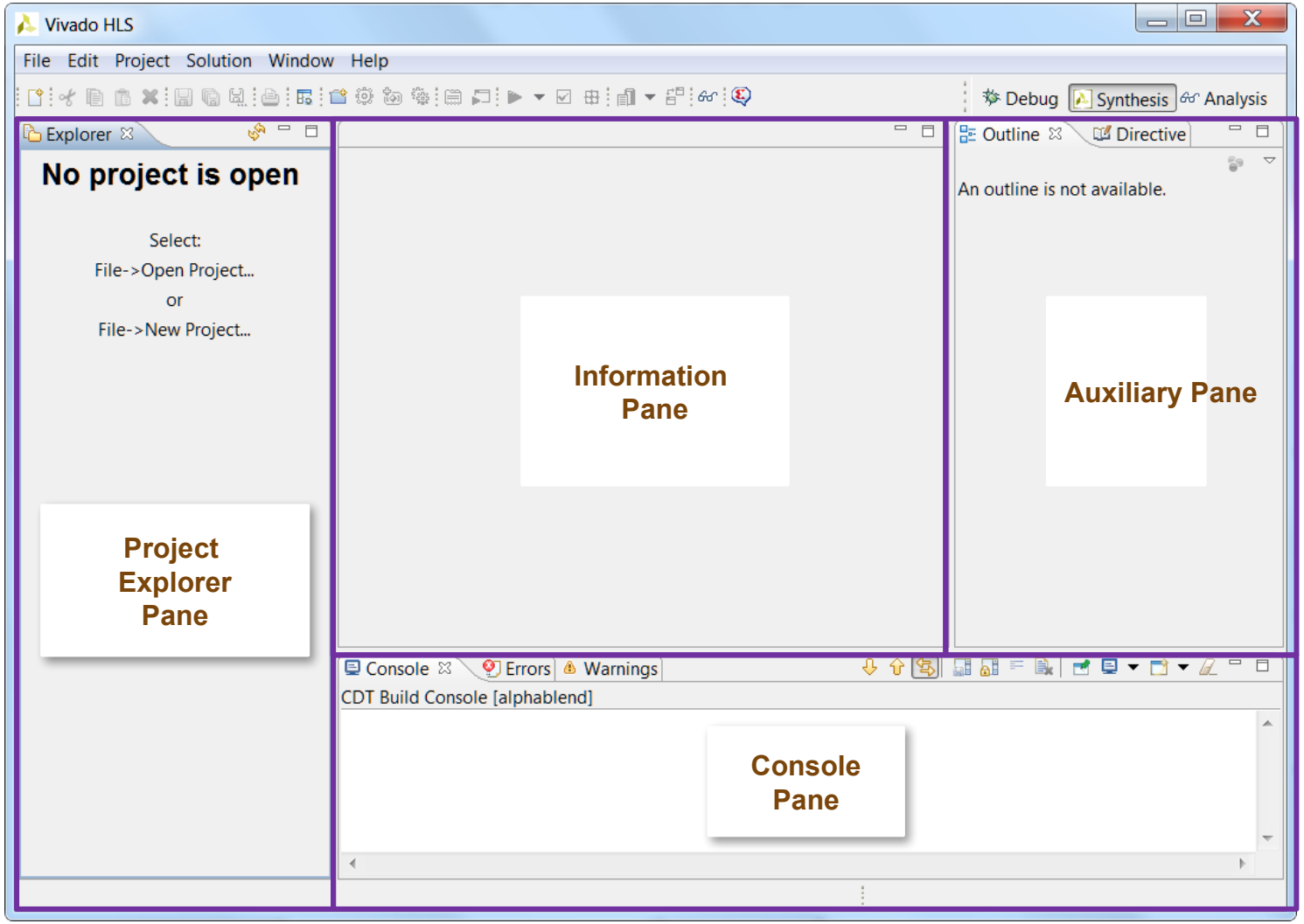
Operating System	Version
Windows	Windows 10 Professional (64-bit) Windows 7 SP1 Professional (64-bit)
Red Hat Linux	RHEL Enterprise Linux 6.6-6.9 (64-bit) RHEL Enterprise Linux 7.2 and 7.3 (64-bit)
SUSE	SUSE Linux Enterprise 11.4 and 12.2 (64-bit)
Cent OS	Cent OS 7.2 and 7.3 (64-bit) Cent OS 6.7, 6.8, and 6.9 (64-bit)
Ubuntu	Ubuntu Linux 16.04.2 LTS (64-bit)

Invoke Vivado HLS from Windows Menu



The first step is to open or create a project

Vivado HLS GUI



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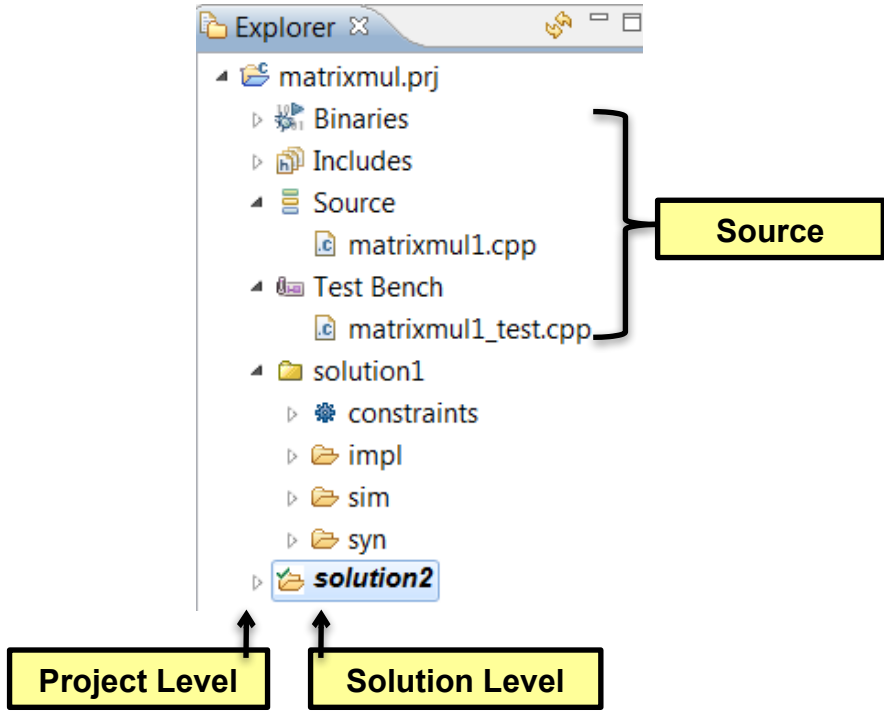
Vivado HLS Projects and Solutions

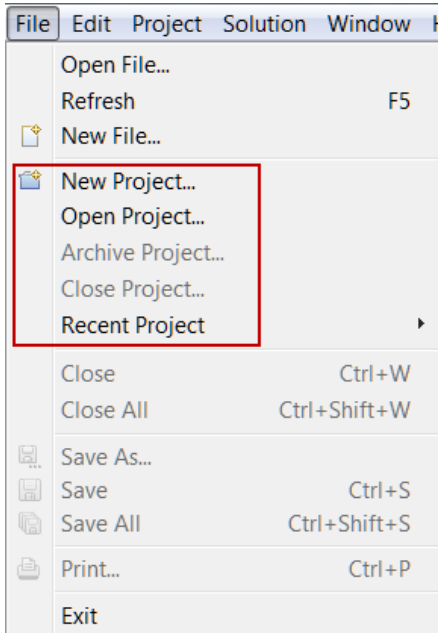
- Vivado HLS is project based
  - A project specifies the source code which will be synthesized
  - Each project is based on one set of source code
  - Each project has a user specified name
- A project can contain multiple solutions
  - Solutions are different implementations of the same code
  - Auto-named solution1, solution2, etc.
  - Supports user specified names
  - Solutions can have different clock frequencies, target technologies, synthesis directives
- Projects and solutions are stored in a hierarchical directory structure
  - Top-level is the project directory
  - The disk directory structure is identical to the structure shown in the GUI project explorer (except for source code location)

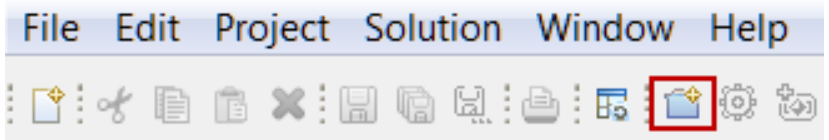


Vivado HLS Step 1: Create or Open a project

Start a new project

- The GUI will start the project wizard to guide you through all the steps





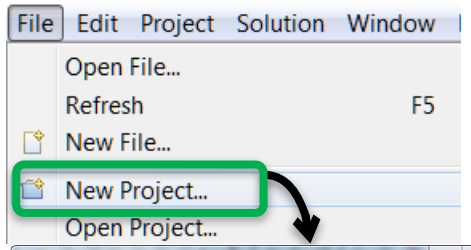
Optionally use the Toolbar Button to Open New Project

Open an existing project

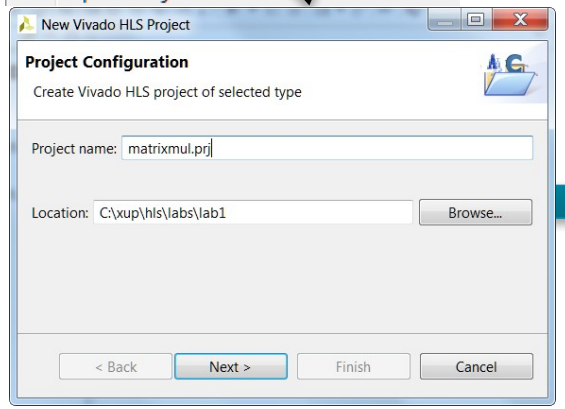
- All results, reports and directives are automatically saved/remembered
- Use “Recent Project” menu for quick access

Project Wizard

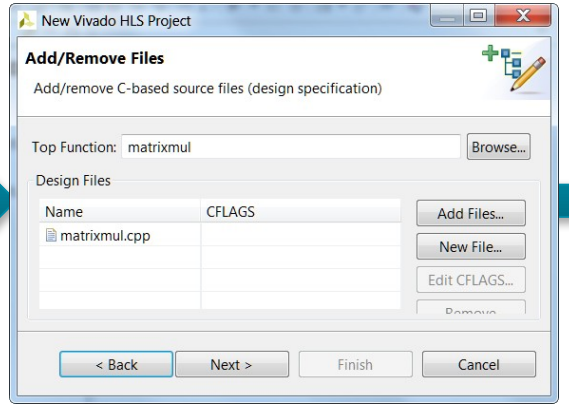
- The Project Wizard guides users through the steps of opening a new project



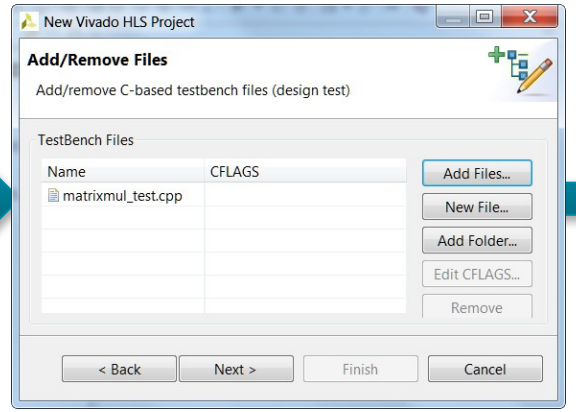
Step-by-step guide …



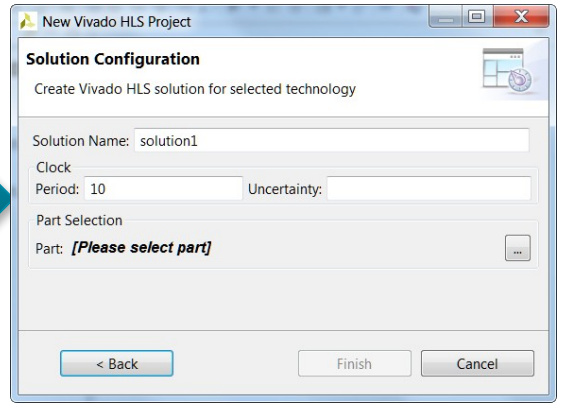
Define project and directory



Add design source files



Specify test bench files



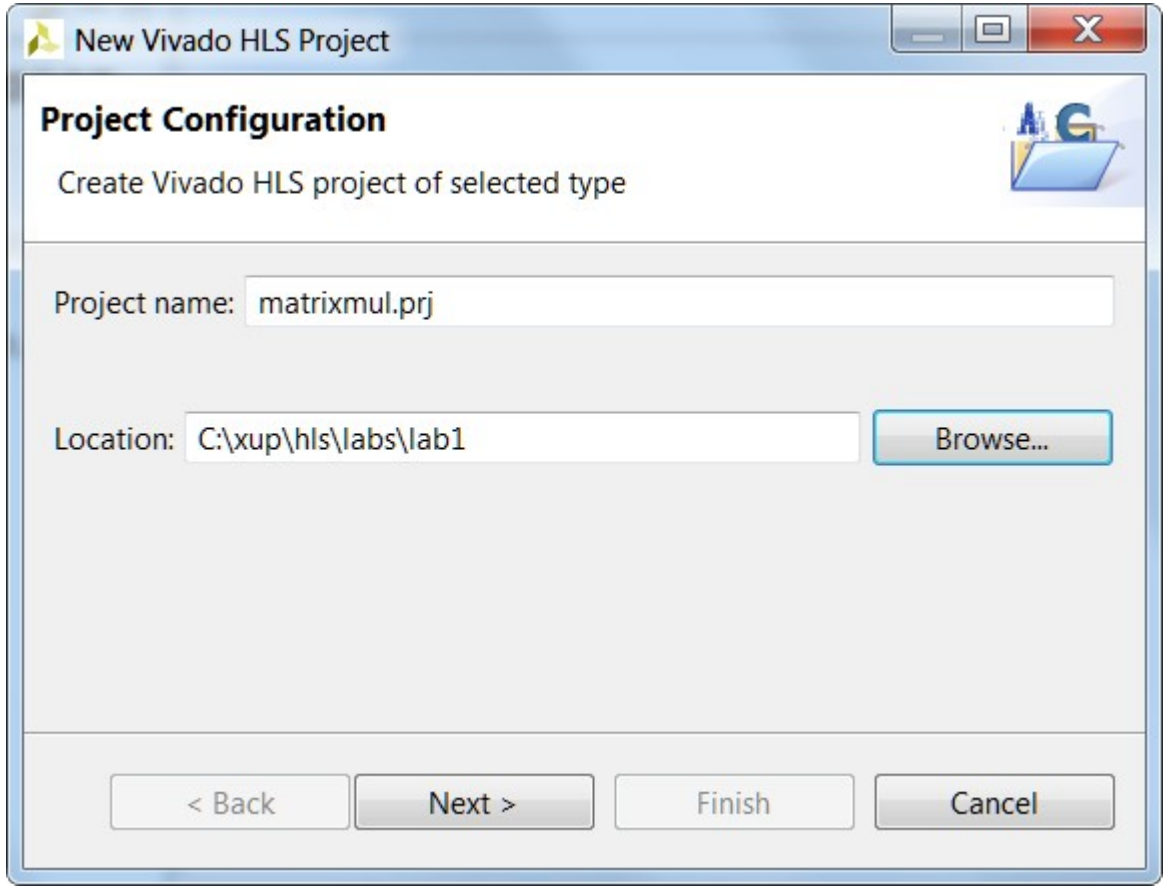
Specify clock and select part

Project Level Information

1st Solution Information

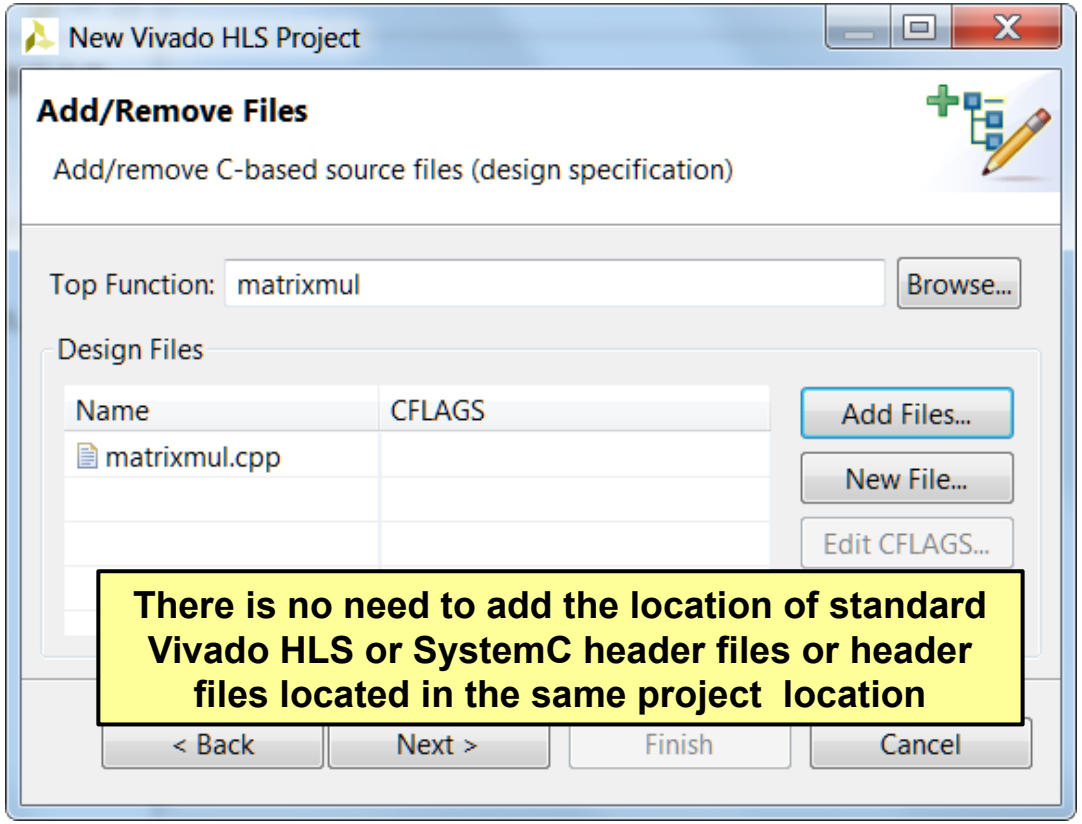
Define Project & Directory

- Define the project name
  - Note, here the project is given the extension .prj
  - A useful way of seeing it's a project (and not just another directory) when browsing
- Browse to the location of the project
  - In this example, project directory "matrixmul.prj" will be created inside directory "lab1"



Add Design Source Files

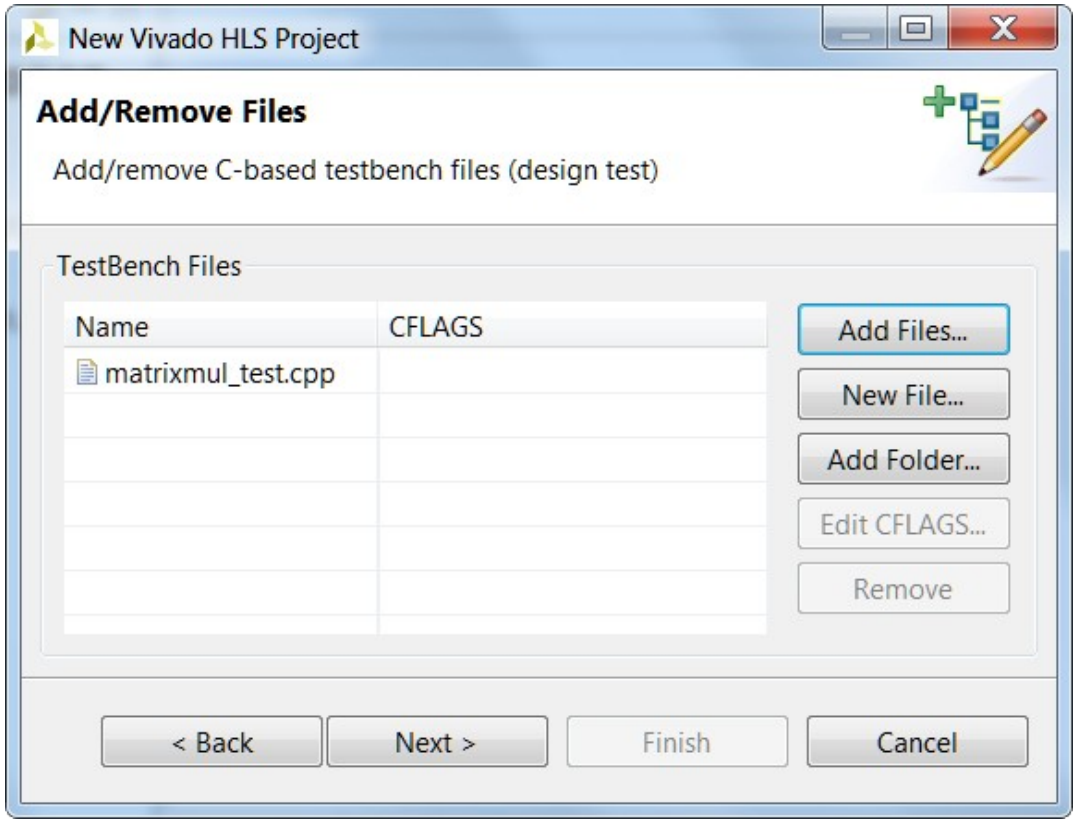
- Add Design Source Files
  - This allows Vivado HLS to determine the top-level design for synthesis, from the test bench and associated files
  - Not required for SystemC designs
- Add Files…
  - Select the source code file(s)
  - The CTRL and SHIFT keys can be used to add multiple files
  - No need to include headers (.h) if they reside in the same directory
- Select File and Edit CFLAGS…
  - If required, specify C compile arguments using the "Edit CFLAGS…"
    - Define macros: `-DVERSION1`
    - Location of any (header) files not in the same directory as the source: -I../include



There is no need to add the location of standard Vivado HLS or SystemC header files or header files located in the same project location

Specify Test Bench Files

- Use “Add Files” to include the test bench
  - Vivado HLS will re-use these to verify the RTL using co-simulation
- And all files referenced by the test bench
  - The RTL simulation will be executed in a different directory (Ensures the original results are not over-written)
  - Vivado HLS needs to also copy any files accessed by the test bench
    - E.g. Input data and output results
- Add Folders
  - If the test bench uses relative paths like “sub_directory/my_file.dat” you can add “sub_directory” as a folder/directory
- Use “Edit CFLAGS…”
  - To add any C compile flags required for compilation



Test benches I

- The test bench should be in a separate file
- Or excluded from synthesis
  - The Macro __SYNTHESIS__ can be used to isolate code which will not be synthesized
    - This macro is defined when Vivado HLS parses any code (-D__SYNTHESIS__)

```
// test.c
#include <stdio.h>
void test (int d[10]) {
  int acc = 0;
  int i;
  for (i=0;i<10;i++) {
    acc += d[i];
    d[i] = acc;
  }
}
#ifndef __SYNTHESIS__
int main () {
  int d[10], i;
  for (i=0;i<10;i++) {
    d[i]   = i;
  }
  test(d);
  for (i=0;i<10;i++) {
    printf("%d %d\n", i, d[i]);
  }
  return 0;
}
#endif
```

Design to be synthesized

Test Bench
Nothing in this ifndef will be read by Vivado HLS
(will be read by gcc)

Test benches II

- Ideal test bench
  - Should be self checking
    - RTL verification will re-use the C test bench
  - If the test bench is self-checking
    - Allows RTL Verification to be run without a requirement to check the results again
  - RTL verification "passes" if the test bench return value is 0 (zero)
    - Actively return a 0 if the simulation passes

```
int main () {
  // Compare results
  int ret = system("diff --brief -w test_data/output.dat test_data/output.golden.dat");
  if (ret != 0) {
        printf("Test failed !!!\n", ret); return 1;
  } else {
        printf("Test passed !\n", ret); return 0;
  }
```

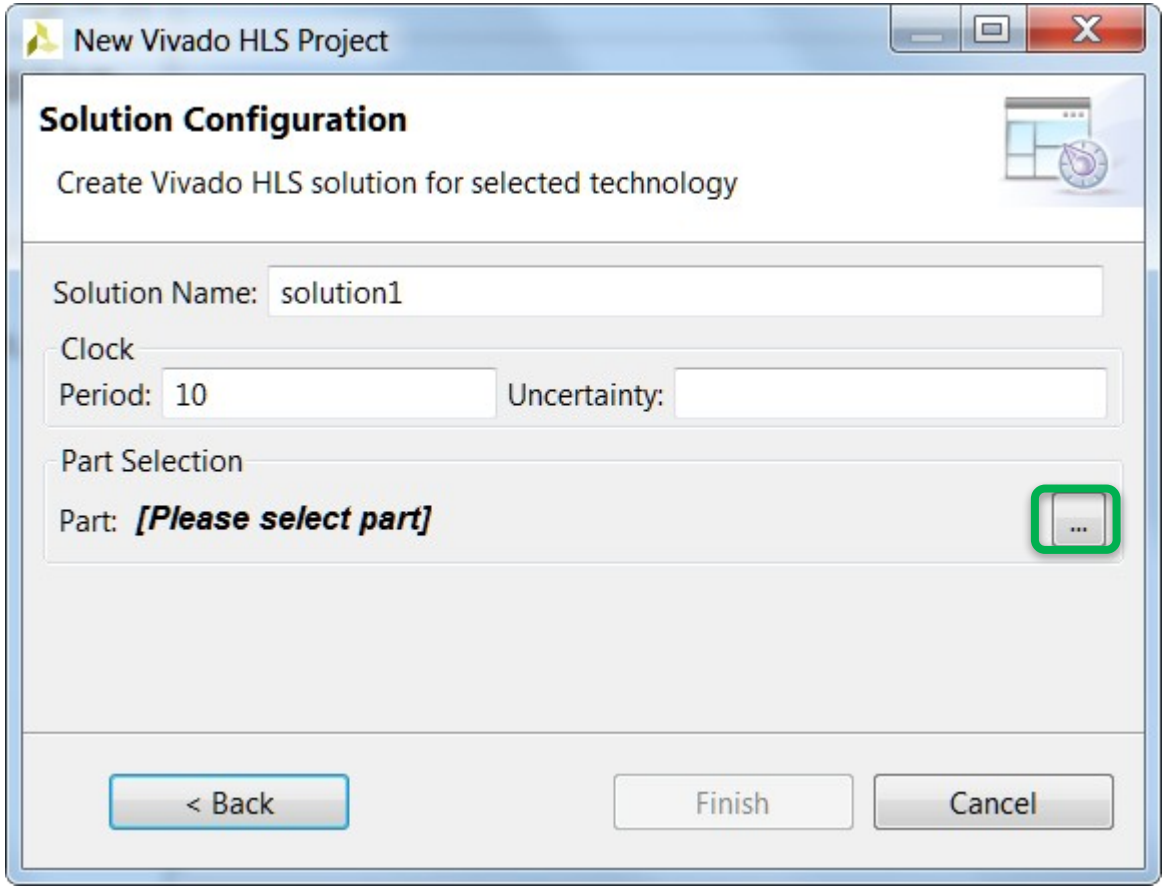
The –w option ensures the "newline" does not cause a difference between Windows and Linux files

  - Non-synthesizable constructs may be added to a synthesize function if __SYNTHESIS__ is used

```
#ifndef __SYNTHESIS__
   image_t *yuv = (image_t *)malloc(sizeof(image_t));
#else // Workaround malloc() calls w/o changing rest of code
   image_t _yuv;
#endif
```

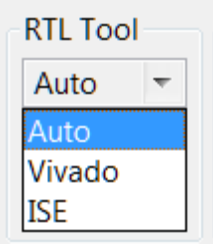
Solution Configuration

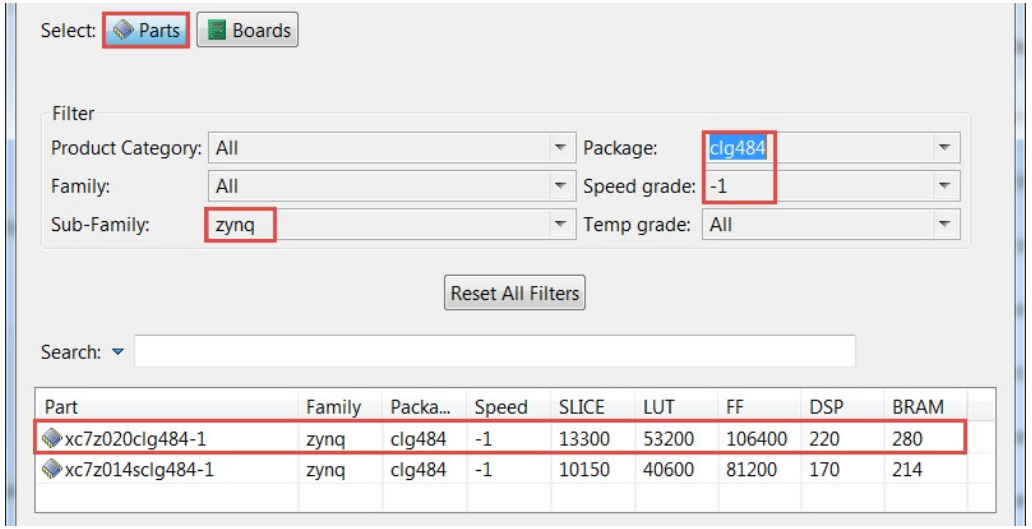
- Provide a solution name
  - Default is solution1, then solution2 etc.
- Specify the clock
  - The clock uncertainty is subtracted from the clock to provide an “effective clock period”
  - Vivado HLS uses the “effective clock period” for Synthesis
  - Provides users defined margin for downstream RTL synthesis, P&R
- Select the part
  - Select a device family after applying filters such as family, package and speed grade (see next slide) or a board after applying boards specify

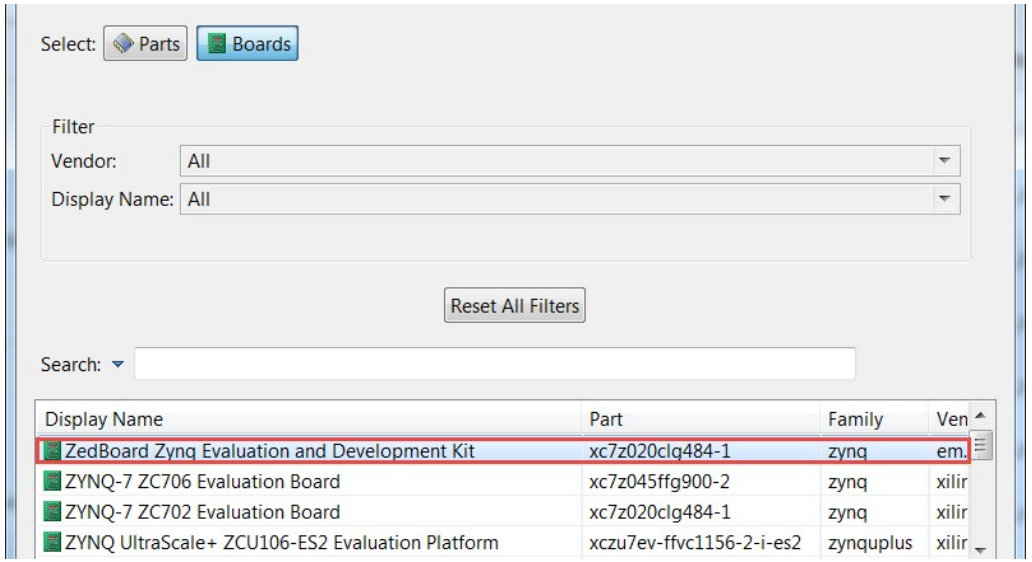


Selecting Part and Implementation Engine

- Select the target part either through Parts or Boards specify
- Select RTL Tools
  - Auto
    - Will select Vivado for 7 Series and Zynq devices
    - Will select ISE for Virtex-6 and earlier families
  - Vivado
  - ISE
    - ISE Design Suite must be installed and must be included in the PATH variable

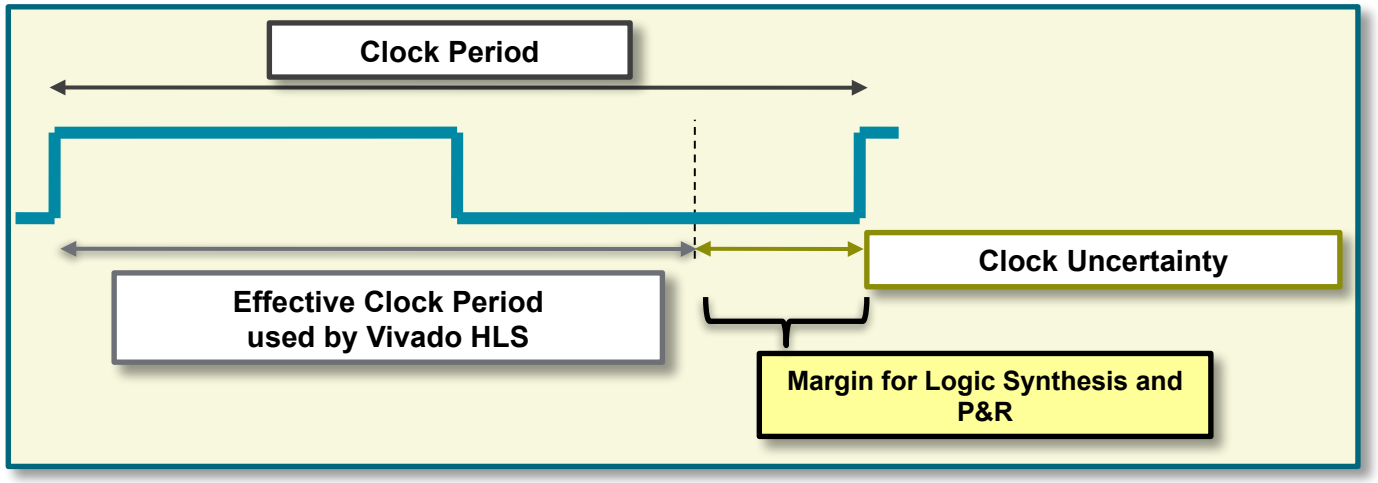






Clock Specification

- Clock frequency must be specified
  - Only 1 clock can be specified for C/C++ functions
  - SystemC can define multiple clocks
- Clock uncertainty can be specified
  - Subtracted from the clock period to give an effective clock period
  - The effective clock period is used for synthesis
    - Should not be used as a design parameter
    - Do not vary for different results: this is your safety margin
  - A user controllable margin to account for downstream RTL synthesis and P&R



A Vivado HLS Project

Vivado HLS - matrixmul.prj (C:\xup\hls\labs\lab1\matrixmul.prj)

File Edit Project Solution Window Help

Debug | Synthesis | Analysis

Explorer

- matrixmul.prj
  - Includes
  - Source
    - matrixmul.cpp
  - Test Bench
  - *solution1*
    - constraints
      - directives.tcl
      - script.tcl

matrixmul.cpp

```
67 #include "matrixmul.h"
68
69 void matrixmul(
70       mat_a_t a[MAT_A_ROWS][MAT_A_COLS],
71       mat_b_t b[MAT_B_ROWS][MAT_B_COLS],
72       result_t res[MAT_A_ROWS][MAT_B_COLS])
73 {
74   // Iterate over the rows of the A matrix
75   Row: for(int i = 0; i < MAT_A_ROWS; i++) {
76     // Iterate over the columns of the B matrix
77     Col: for(int j = 0; j < MAT_B_COLS; j++) {
78       // Do the inner product of a row of A and col of
79 //      res[i][j] = 0;
80       Product: for(int k = 0; k < MAT_B_ROWS; k++) {
81         res[i][j] += a[i][k] * b[k][j];
82       }
83     }
84   }
85 }
```

Outline | Directive

- matrixmul.h
- matrixmul(mat_a_t[][], mat_b_t[][], result_t[][]) : void

Console | Errors | Warnings

CDT Build Console [matrixmul.prj]

Writable | Smart Insert | 2 : 1

Project Explorer
Project files displayed in a hierarchal view

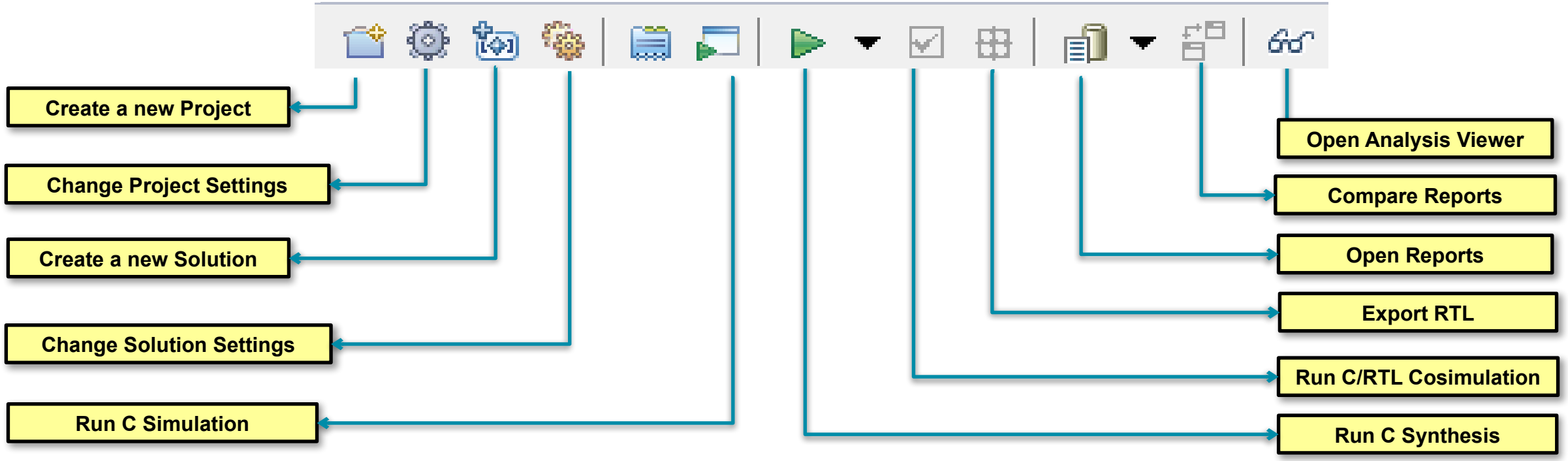
Information Pane
Can view and edit any file from the Project Explorer

Auxiliary Pane
Cross-referenced with the Information Pane (here it shows objects in the source code)

Console Pane
Displays Vivado HLS run time messages

Vivado HLS GUI Toolbar

- The primary commands have toolbar buttons
  - Easy access for standard tasks
  - Button highlights when the option is available
    - E.g. cannot perform C/RTL simulation before synthesis



Files: Views, Edits & Information

Vivado HLS - matrixmul.prj (C:\xup\hls\labs\lab1\matrixmul.prj)

File Edit Project Solution Window Help

Debug | Synthesis | Analysis

Explorer

- matrixmul.prj
  - Includes
  - Source
    - matrixmul.cpp
  - Test Bench
  - solution1
    - constraints
      - directives.tcl
      - script.tcl

matrixmul.cpp

```
67 #include "matrixmul.h"
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69 void matrixmul(
70     mat_a_t a[MAT_A_ROWS][MAT_A_COLS],
71     mat_b_t b[MAT_B_ROWS][MAT_B_COLS],
72     result_t res[MAT_A_ROWS][MAT_B_COLS])
73 {
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75   Row: for(int i = 0; i < MAT_A_ROWS; i++) {
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77     Col: for(int j = 0; j < MAT_B_COLS; j++) {
78       // Do the inner product of a row of A and col of
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81         res[i][j] += a[i][k] * b[k][j];
82       }
83     }
84   }
85 }
```

Outline | Directive

- matrixmul.h
- matrixmul(mat_a_t[][], mat_b_t[][], result_t[][]) : void

Console | Errors | Warning

CDT Build Console [matrixmul.prj]

Writable | Smart Insert | 2 : 1

Open file and it will display in the information pane

The Auxiliary pane is context sensitive with respect to the information pane

Here it displays elements in the code which can have directives specified on them

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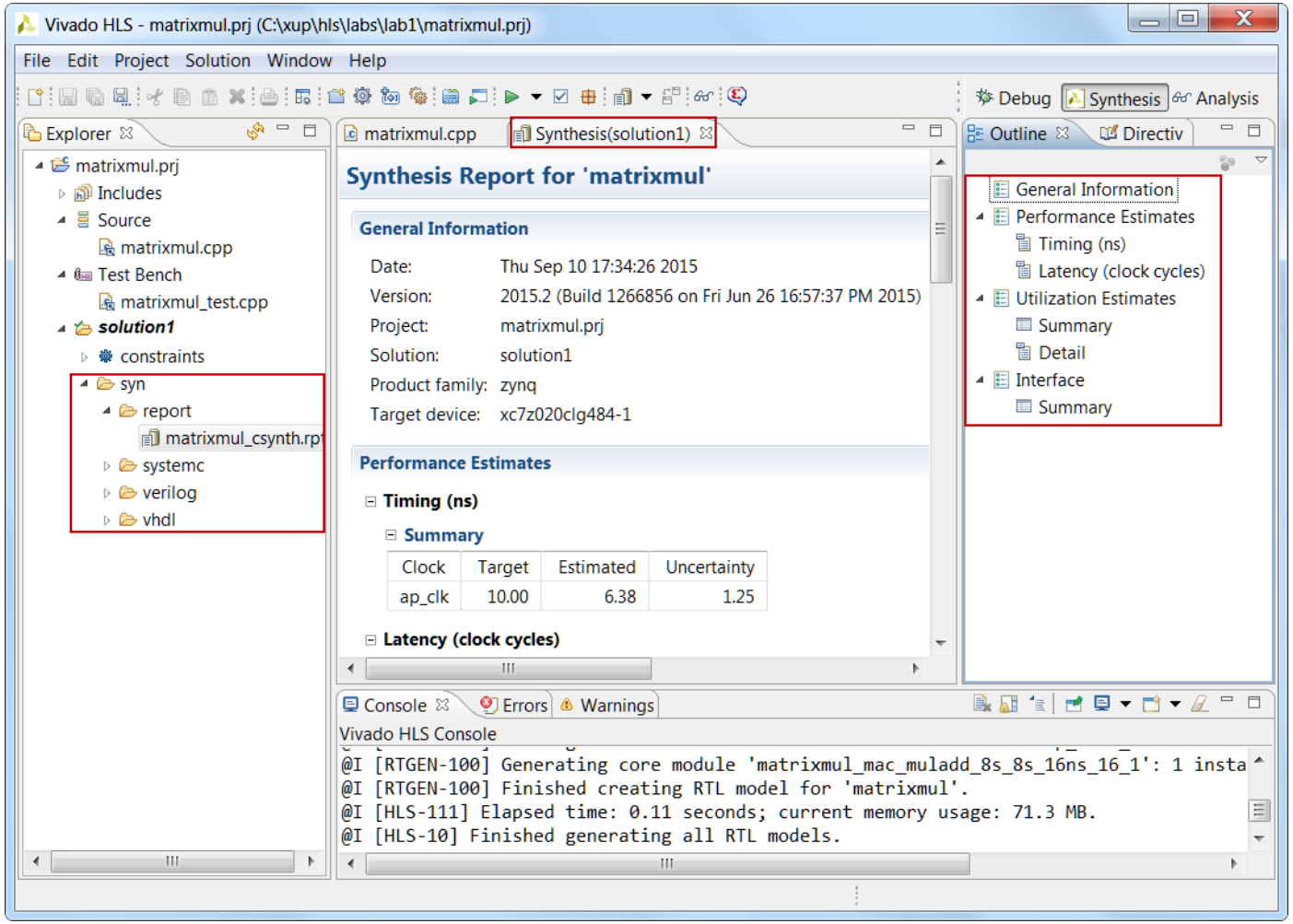
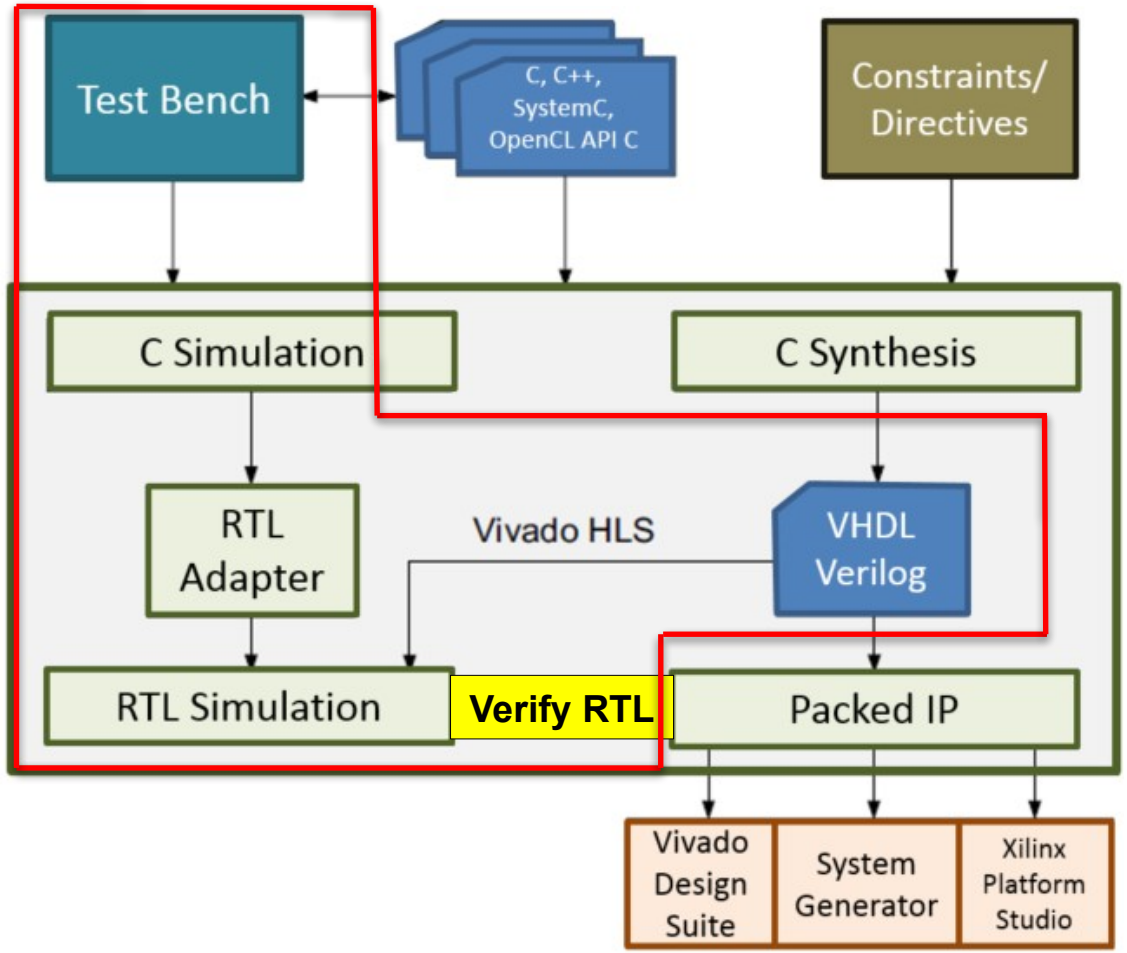
Synthesis

- Run C Synthesis
- Console
  - Will show run time information
  - Examine for failed constraints
- A “syn” directory is created
  - Verilog, VHDL & SystemC RTL
  - Synthesis reports for all non-inlined functions
- Report opens automatically
  - When synthesis completes
- Report is outlined in the Auxiliary pane



Vivado HLS : RTL Verification



RTL output in Verilog and VHDL

Automatic re-use of the C-level test bench

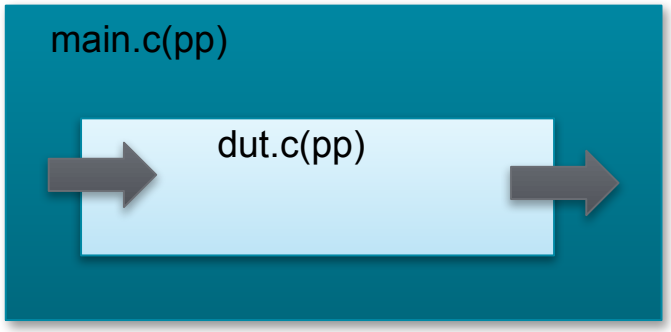
RTL verification can be executed from within Vivado HLS

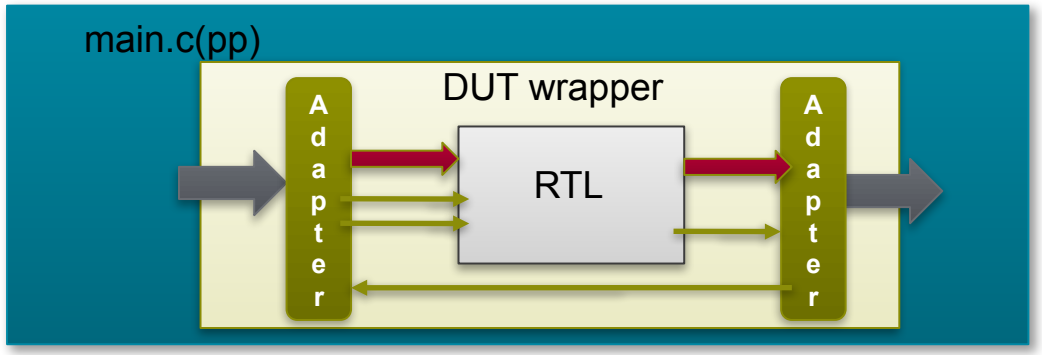
Support for Xilinx simulators (XSim and ISim) and 3rd party HDL simulators in automated flow

RTL Verification: Under-the-Hood

RTL Co-Simulation

- Vivado HLS provides RTL verification
- Creates the wrappers and adapters to re-use the C test bench





- Prior to synthesis
  - Test bench
  - Top-level C function
- After synthesis
  - Test bench
  - Wrapper created by Vivado HLS
  - Adapters created by Vivado HLS
  - RTL output from Vivado HLS
    - Verilog or VHDL

There is no HDL test bench created

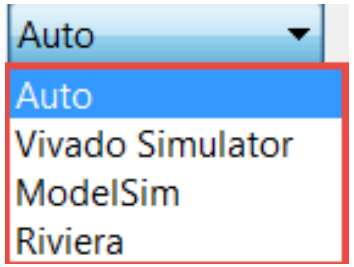
RTL Verification Support

- Vivado HLS RTL Output
  - Vivado HLS outputs RTL in SystemC, Verilog and VHDL
    - The SystemC output is at the RT Level
    - The input is not transformed to SystemC at the ESL
- RTL Verification with SystemC
  - The SystemC RTL output can be used to verify the design without the need for a HDL simulator and license
- HDL Simulation Support
  - Vivado HLS supports HDL simulators on both Windows & Linux
  - The 3rd party simulator executable must be in OS search path

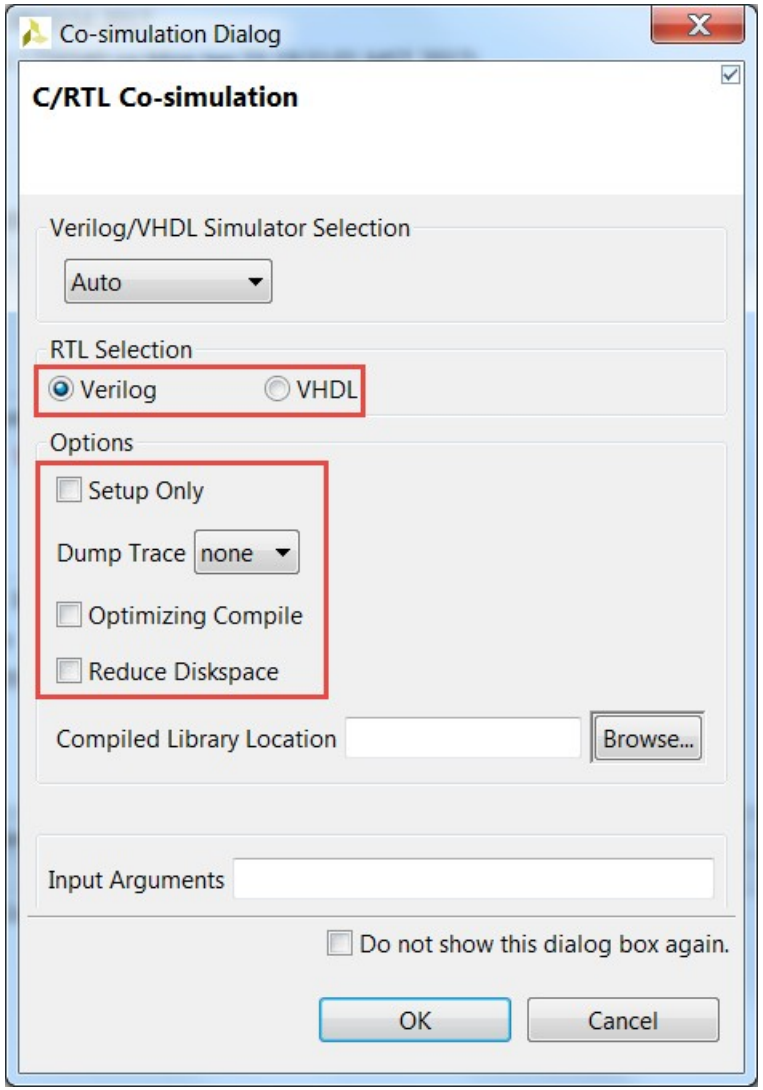
Simulator	Linux	Windows	SUSE	Ubuntu
XSim (Vivado Simulator)	Supported	Supported	Supported	Supported
ISim (ISE Simulator)	Supported	Supported	Supported	Supported
ModelSim	Supported	Supported	Supported	N/A
Synopsys VCS	Supported	N/A	Supported	N/A
Cadence NCSim	Supported	N/A	Supported	N/A
Riviera	Supported	Supported	Supported	N/A

C/RTL Co-simulation

- Start Simulation
  - Opens the dialog box
- Select the RTL
  - Verilog and VHDL require the appropriate simulator
    - Select the desired simulator

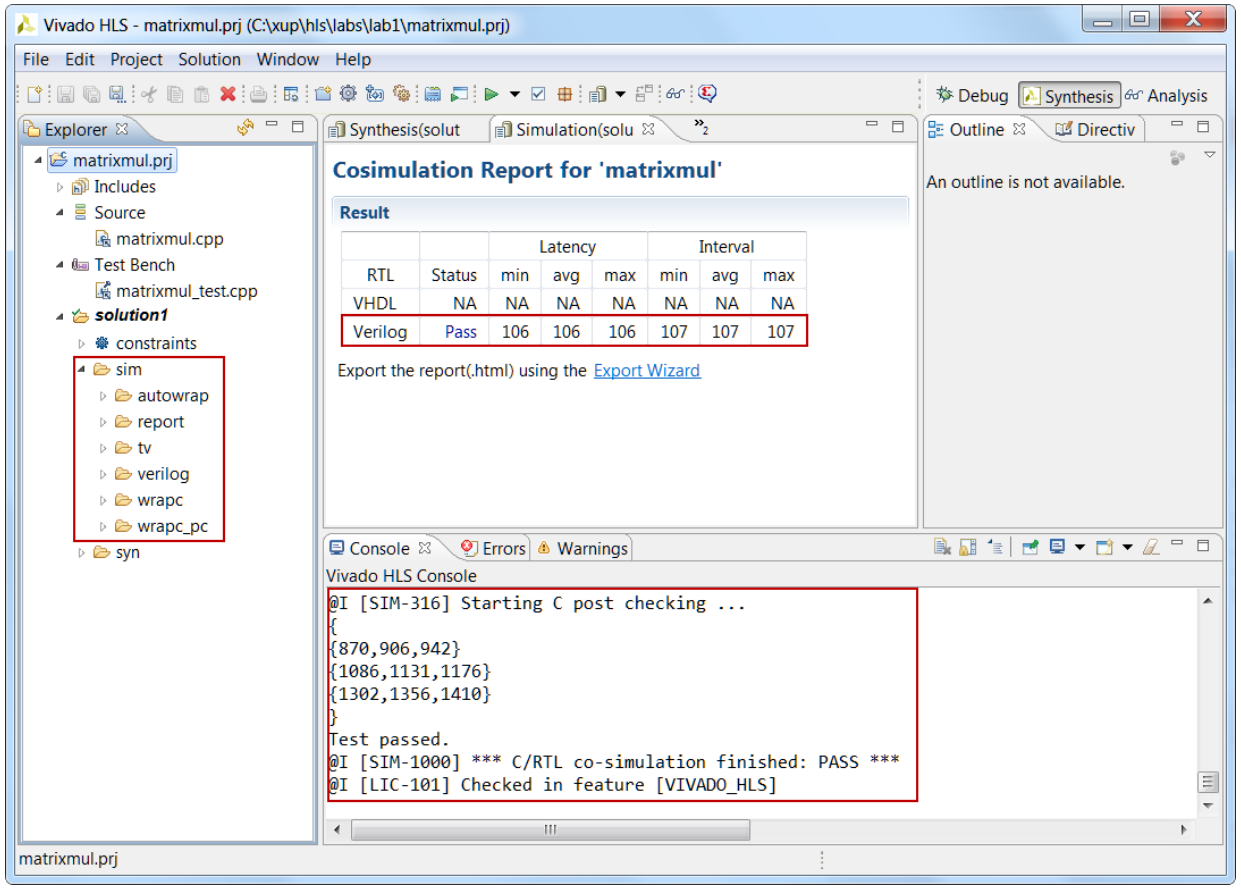


- Options
  - Can output trace file (VCD format)
  - Optimize the C compilation & specify test bench linker flags
  - The “setup only” option will not execute the simulation
- OK will run the simulator
  - Output files will be created in a “sim” directory

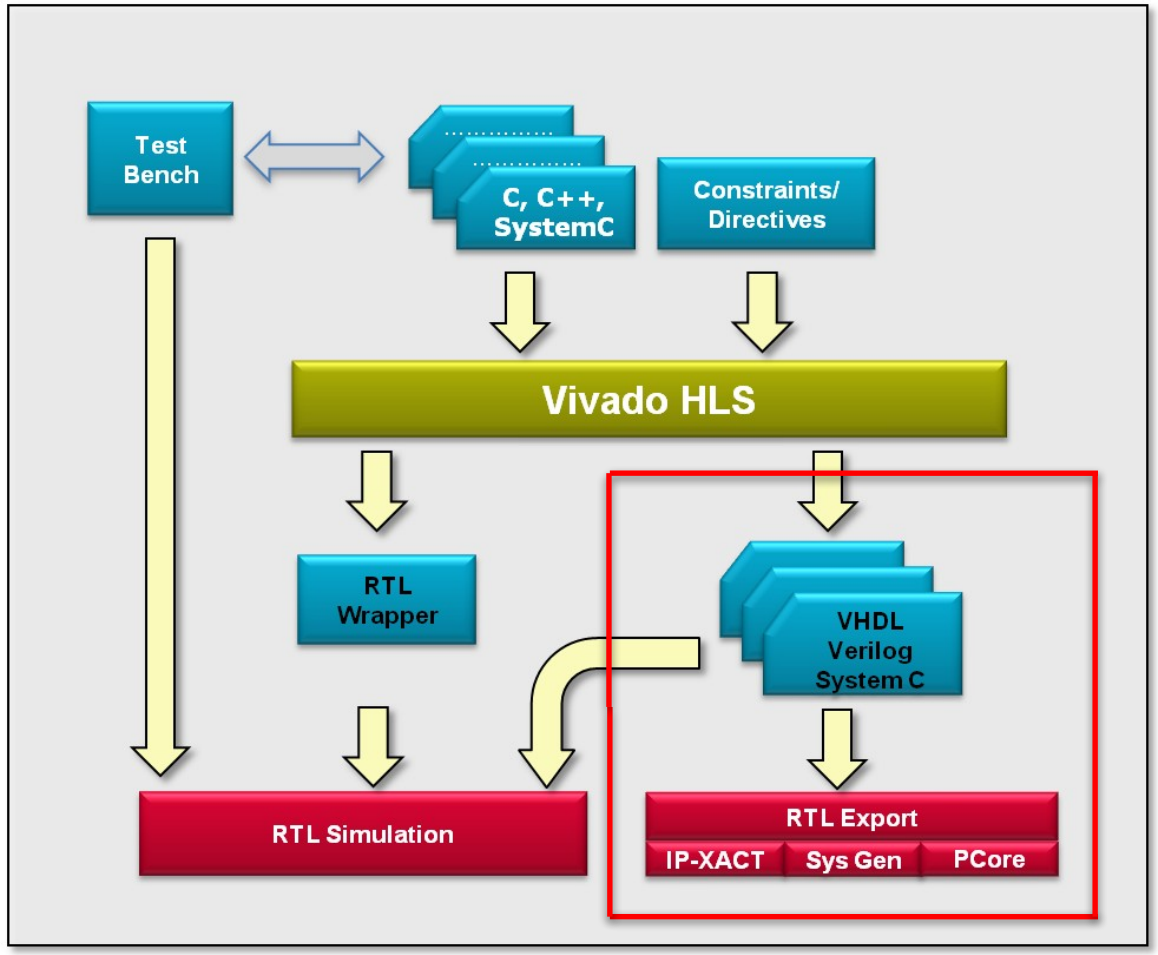


Simulation Results

- Simulation output is shown in the console
- Expect the same test bench response
  - If the C test bench plots, it will with the RTL design (but slower)
- Sim Directory
  - Will contain a sub-directory for each RTL which is verified
- Report
  - A report is created and opened automatically



Vivado HLS : RTL Export



RTL output in Verilog, VHDL and SystemC

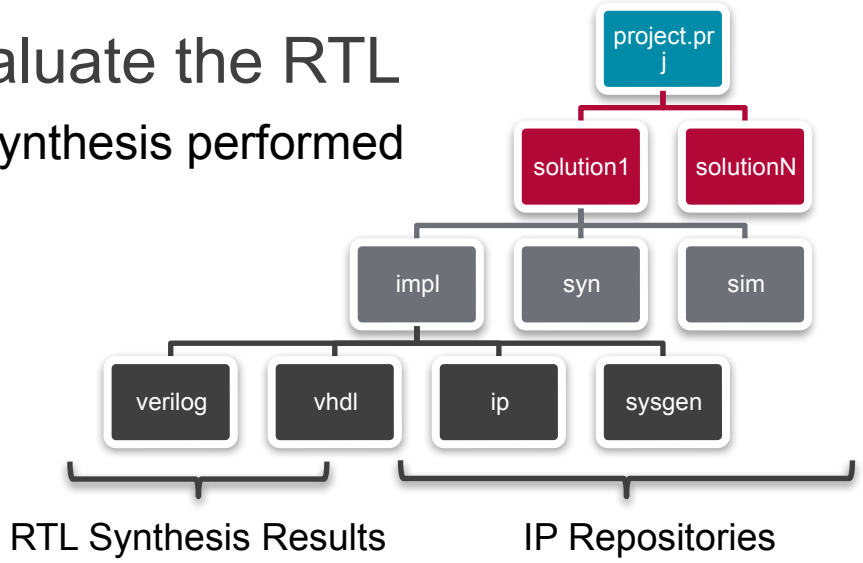
Scripts created for RTL synthesis tools

RTL Export to IP-XACT, SysGen, and Pcore formats

IP-XACT and SysGen => Vivado HLS for 7 Series and Zynq families
PCore => Only Vivado HLS Standalone for all families

RTL Export: Synthesis

- RTL Synthesis can be performed to evaluate the RTL
  - IP-XACT and System Generator formats: Vivado synthesis performed
  - Pcore format: ISE synthesis is performed



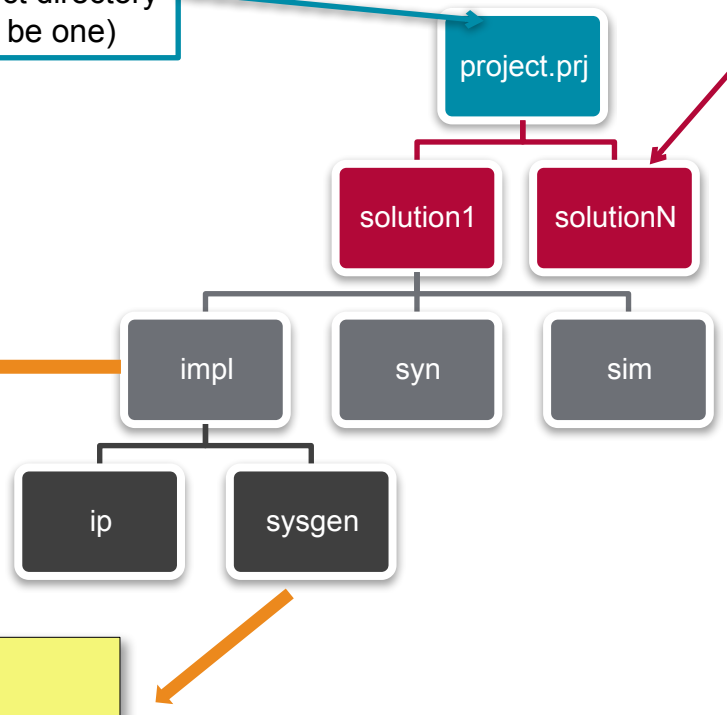
- RTL synthesis results are not included with the IP package
  - Evaluate step is provided to give confidence
    - Timing will be as estimate (or better)
    - Area will be as estimated (or better)
  - Final RTL IP is synthesized with the rest of the RTL design

RTL Export: IP Repositories

- IP can be imported into other Xilinx tools

Project Directory
Top-level project directory (there must be one)

Solution directories
There can be multiple solutions for each project. Each solution is a different implementation of the same (project) source code

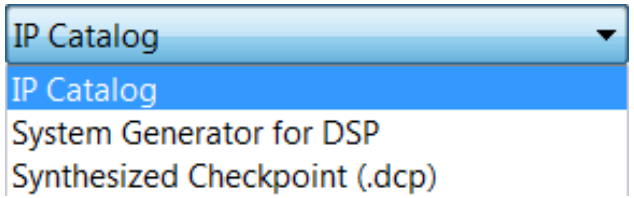


In Vivado :
1. Project Manager > IP Catalog
2. Add IP to import this block
3. Browse to the zip file inside “ip”

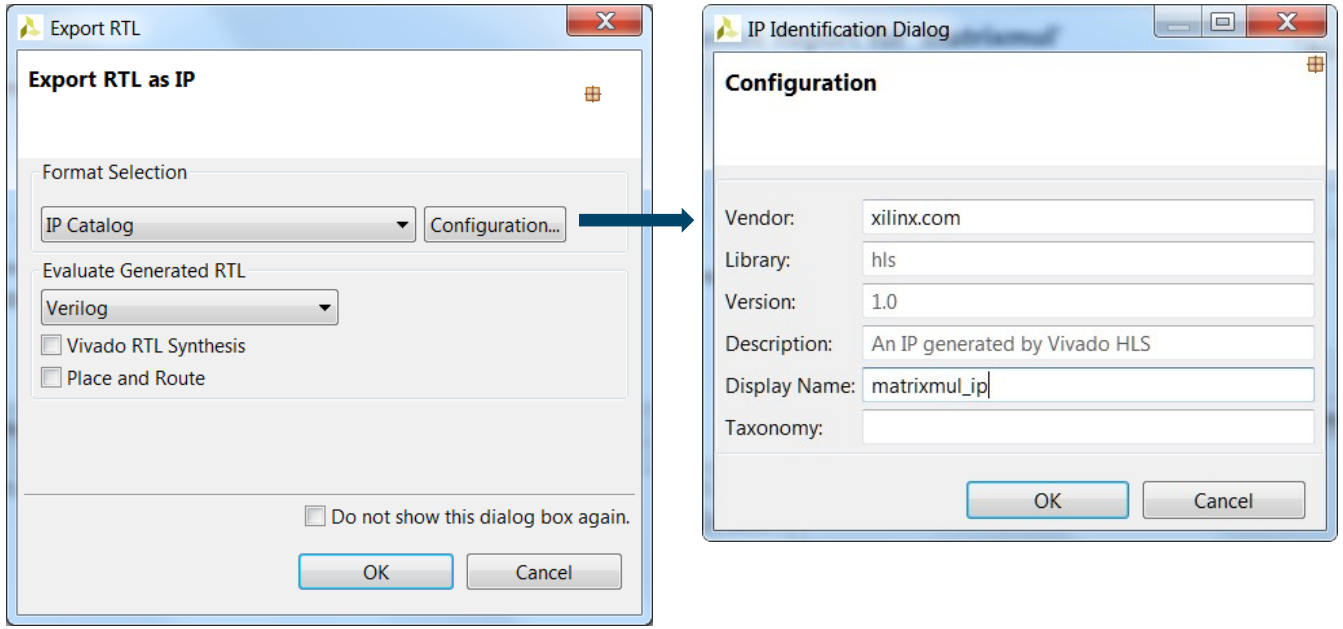
In System Generator :
1. Use XilinxBlockAdd
2. Select Vivado_HLS block type
3. Browse to the solution directory

RTL Export for Implementation

- Click on Export RTL
  - Export RTL Dialog opens
- Select the desired output format



- Optionally, configure the output
- Select the desired language
- Optionally, click on Vivado RTL Synthesis and Place and Route options for invoking implementation tools from within Vivado HLS
- Click OK to start the implementation



RTL Export (Place and Route Option) Results

- Impl directory created
  - Will contain a sub-directory for each RTL which is synthesized
- Report
  - A report is created and opened automatically

```
Implementation tool: Xilinx Vivado v.2017.4
Project:             matrixmul.prj
Solution:            solution1
Device target:       xc7z020clg484-1
Report date:         Tue Feb 13 10:29:28 -0800 2018

#=== Post-Implementation Resource usage ===
SLICE:           10
LUT:             34
FF:              27
DSP:              1
BRAM:             0
SRL:              0
#=== Final timing ===
CP required:    10.000
CP achieved post-synthesis:    3.019
CP achieved post-implementation:    3.728
Timing met
INFO: [Common 17-206] Exiting Vivado at Tue Feb 13 10:29:28 2018...
Finished export RTL.
```

Export Report for 'matrixmul'

General Information

Report date:	Tue Feb 13 10:29:28 -0800 2018
Project:	matrixmul.prj
Solution:	solution1
Device target:	xc7z020clg484-1
Implementation tool:	Xilinx Vivado v.2017.4

Resource Usage

	VHDL
SLICE	10
LUT	34
FF	27
DSP	1
BRAM	0
SRL	0

Final Timing

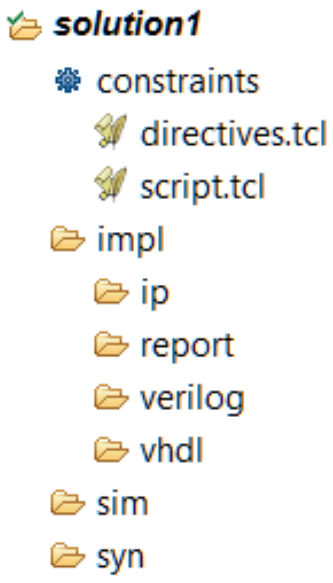
	VHDL
CP required	10.000
CP achieved post-synthesis	3.019
CP achieved post-implementation	3.728

Timing met

RTL Export Results (Place and Route Option Unchecked)

- Impl directory created
  - Will contain a sub-directory for both VHDL and Verilog along with the ip directory
- No report will be created
- Observe the console
  - No packing, routing phases

```
Starting export RTL ...
C:/Xilinx/Vivado/2017.4/bin/vivado_hls.bat C:/xup/hls/labs/lab1/matrixmul.prj/solution1/export.tcl
INFO: [HLS 200-10] Running 'C:/Xilinx/Vivado/2017.4/bin/unwrapped/win64.o/vivado_hls.exe'
INFO: [HLS 200-10] For user 'parimalp' on host 'xsjparimalp31' (Windows NT_amd64 version 6.1) on T
INFO: [HLS 200-10] In directory 'C:/xup/hls/labs/lab1'
INFO: [HLS 200-10] Opening project 'C:/xup/hls/labs/lab1/matrixmul.prj'.
INFO: [HLS 200-10] Opening solution 'C:/xup/hls/labs/lab1/matrixmul.prj/solution1'.
INFO: [SYN 201-201] Setting up clock 'default' with a period of 10ns.
INFO: [HLS 200-10] Setting target device to 'xc7z020clg484-1'
INFO: [IMPL 213-8] Exporting RTL as a Vivado IP.
```

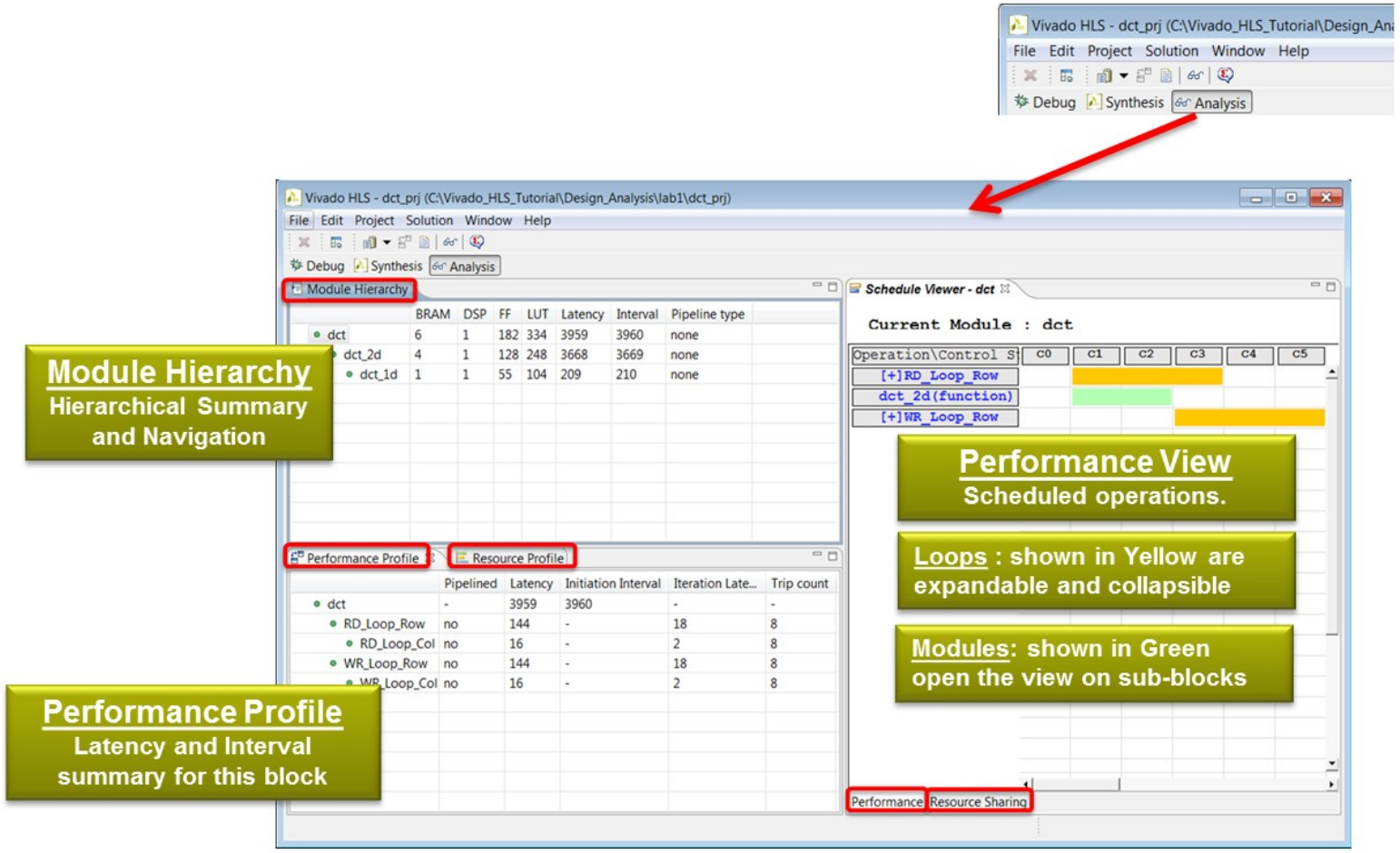


Outline

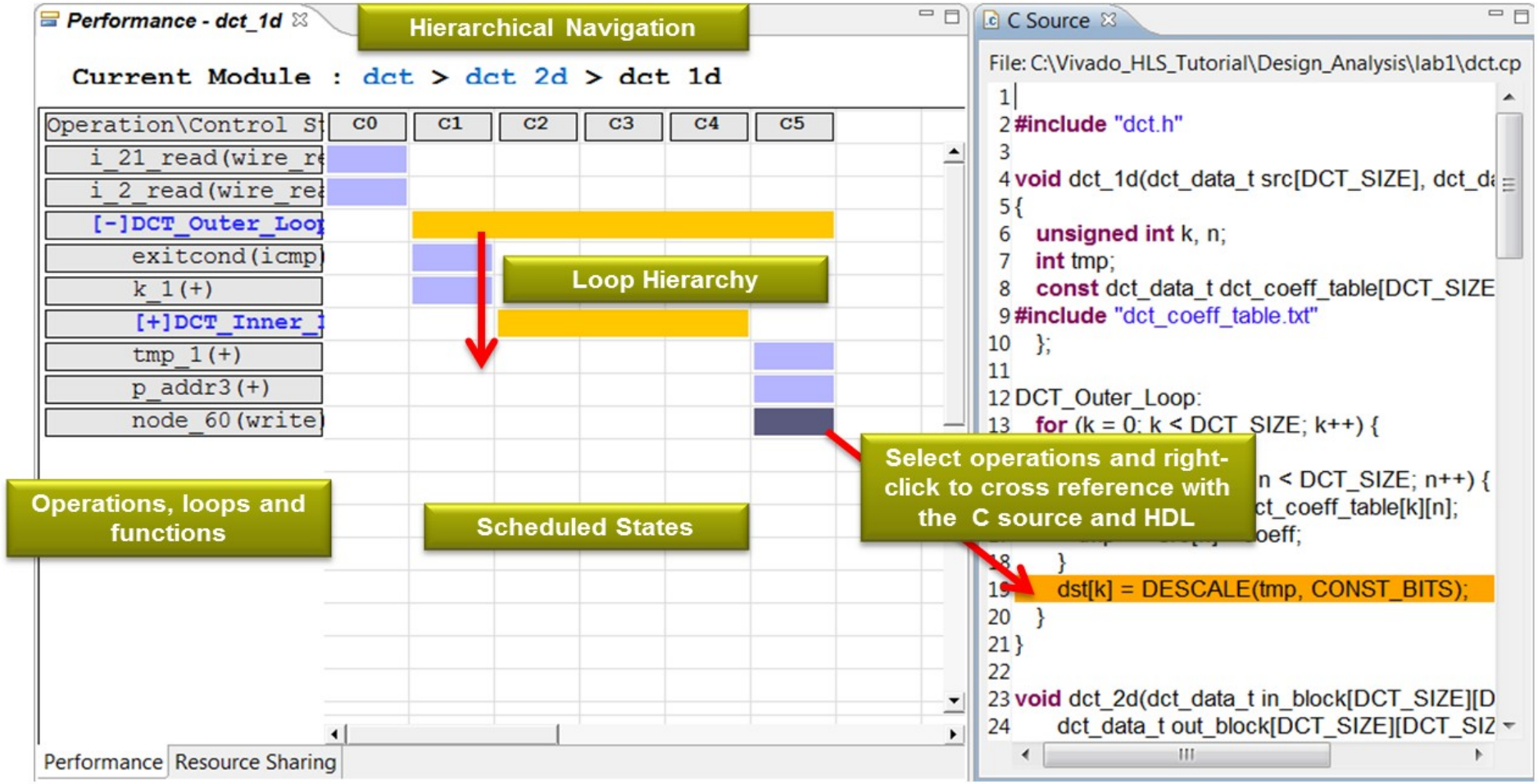
- Invoking Vivado HLS
- Project Creation using Vivado HLS
- Synthesis to IPXACT Flow
- *Design Analysis*
- Other Ways to use Vivado HLS
- Summary

Analysis Perspective

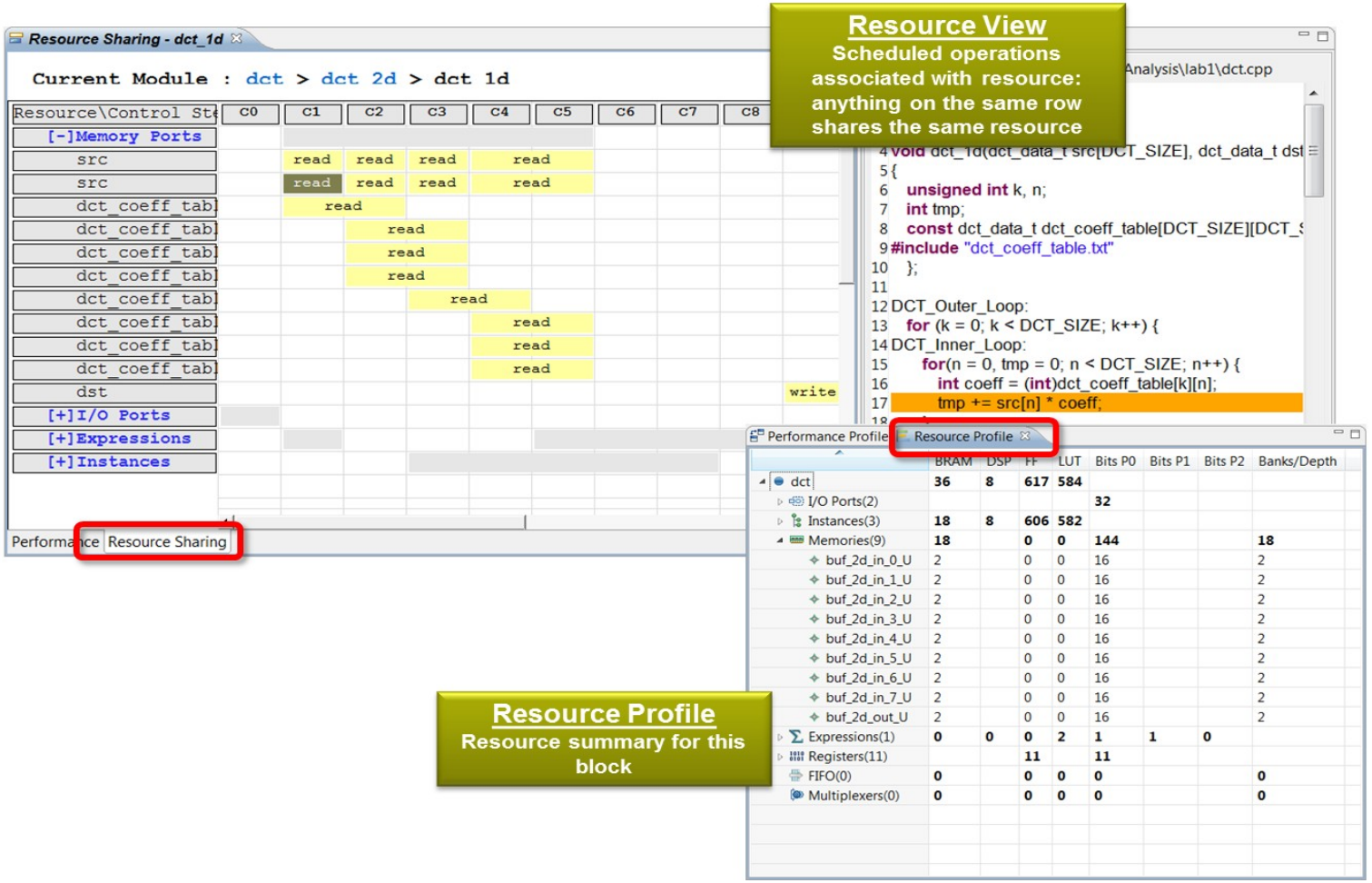
- Perspective for design analysis
  - Allows interactive analysis



Performance Analysis



Resources Analysis



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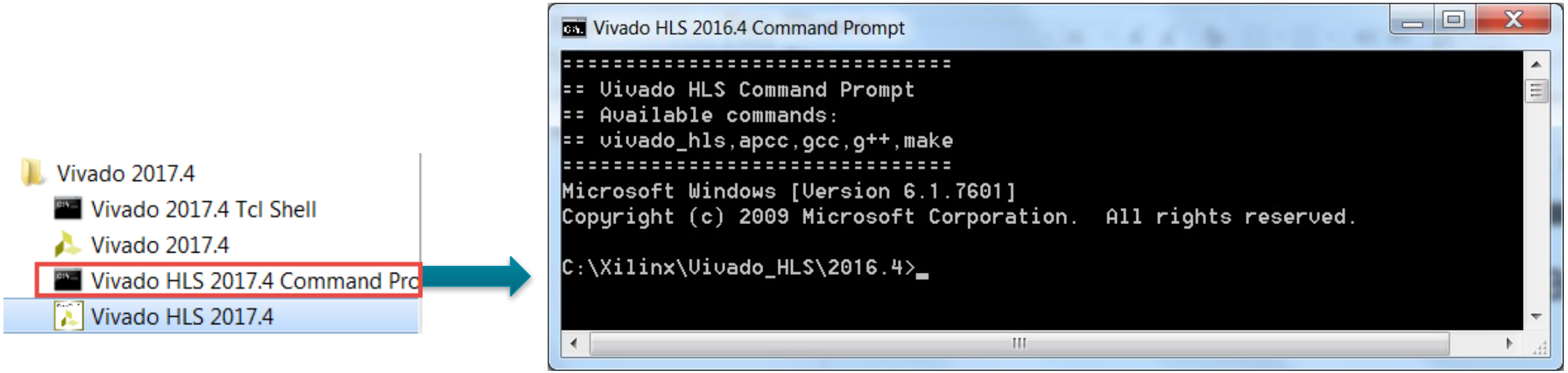
Command Line Interface: Batch Mode

- Vivado HLS can also be run in batch mode
  - Opening the Command Line Interface (CLI) will give a shell



  - Supports the commands required to run Vivado HLS & pre-synthesis verification (gcc, g++, apcc, make)

Using Vivado HLS CLI

- Invoke Vivado HLS in interactive mode
  - Type Tcl commands one at a time

```
> vivado_hls  –i
```

- Execute Vivado HLS using a Tcl batch file
  - Allows multiple runs to be scripted and automated

```
> vivado_hls  –f run_aesl.tcl
```

- Open an existing project in the GUI
  - For analysis, further work or to modify it

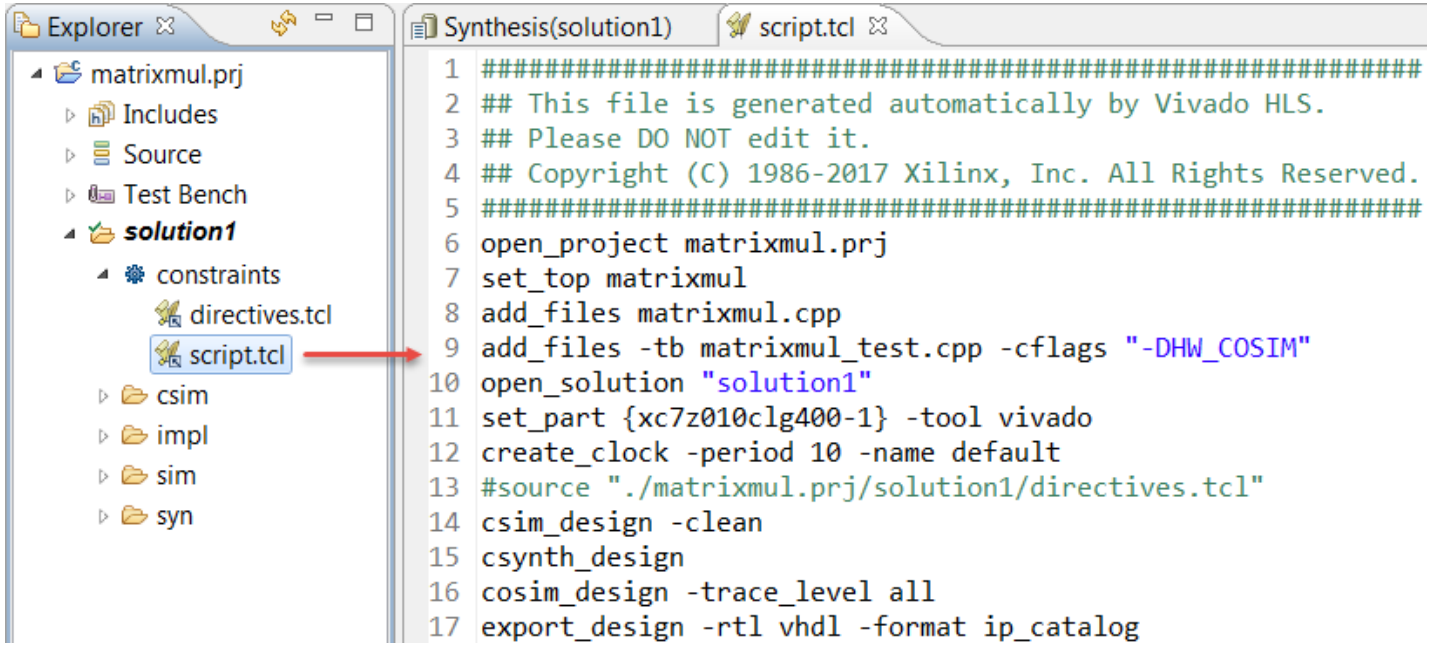
```
> vivado_hls  –p my.prj
```

- U GUI

```
> vivado_hls
```

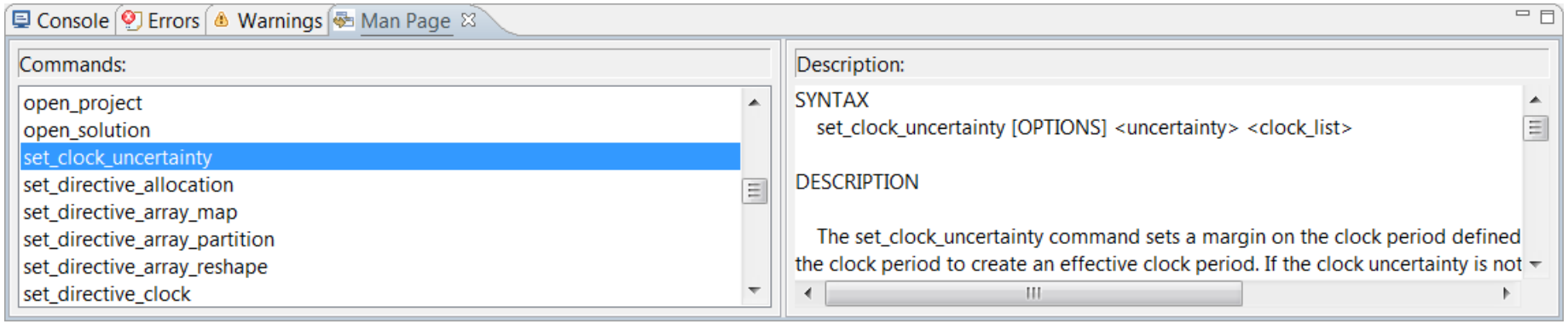
Using Tcl Commands

- When the project is created
  - All Tcl command to run the project are created in script.tcl
    - User specified directives are placed in directives.tcl
  - Use this as a template from creating Tcl scripts
    - Uncomment the commands before running the Tcl script



Help

- Help is always available
  - The Help Menu
  - Opens User Guide, Reference Guide and Man Pages



- In interactive mode
  -

```
Vivado_hls> help add_files

SYNOPSIS
   add_files  [OPTIONS] <src_files>
Etc…
```

Auto-Complete all commands using the tab key

Outline

- Invoking Vivado HLS
- Project Creation using Vivado HLS
- Synthesis to IPXACT Flow
- Design Analysis
- Other Ways to use Vivado HLS
- *Summary*

Summary

- Vivado HLS can be run under Windows 7/8.1, Red Hat Linux, SUSE OS, and Ubuntu
- Vivado HLS can be invoked through GUI and command line in Windows OS, and command line in Linux
- Vivado HLS project creation wizard involves
  - Defining project name and location
  - Adding design files
  - Specifying testbench files
  - Selecting clock and technology
- The top-level module in testbench is main() whereas top-level module in the design is the function to be synthesized

Summary

- Vivado HLS project directory consists of
  - *.prj project file
  - Multiple solutions directories
  - Each solution directory may contain
    - impl, synth, and sim directories
    - The impl directory consists of ip, verilog, and vhdl folders
    - The synth directory consists of reports, vhdl, and verilog folders
    - The sim directory consists of testbench and simulation files