Improving Area and Resources

Vivado HLS 2013.3 Version

Objectives

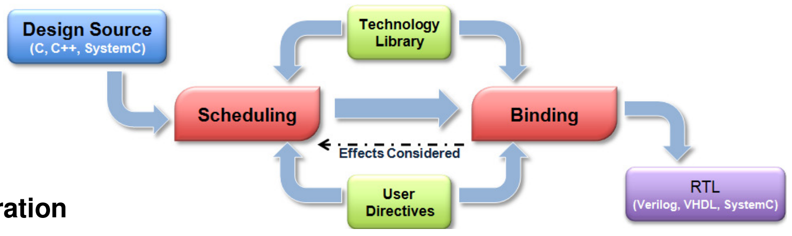
- **After completing this module, you will be able to:**
  - Describe how arbitrary precision data types can reduce resource utilization
  - List various area optimization techniques
  - List means by which resource utilization can be reduced

Outline

- ***Optimizing Resource Utilization***
- **Reducing Area Usage**
- **Summary**

Review: Control Scheduling & Binding

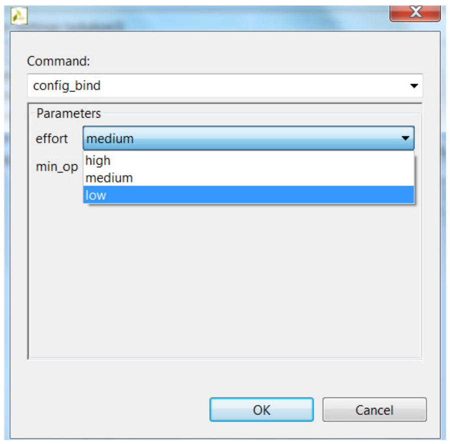
- **Scheduling & Binding**
  - Scheduling and Binding are the processes at the heart of HLS



- **Binding configuration**
  - Can be used to minimize the number of operations
- **The allocation directive**
  - Can be used to limit the number of operation in scheduling & binding stages
- **The resource directive**
  - Can be used to specify which cores are to be used during binding

Configuring Binding

- **Binding is controlled via a configuration command**
  - The effort levels determine how much time is spent trying to map many operators onto fewer cores
  - As with all effort levels, they are worth using if you can see the design close to what is required
    - Else the tool will spend time exploring for possibilities
    - And simply increase run time
    - Use efforts judiciously
- **Binding can be configured to minimize specific operators**
  - Can be used to direct Vivado HLS to synthesize with the minimum number of operations
  - The configuration command overrides muxing costs and can be used to force sharing
    - Works on all scopes in a design



Command: config_bind

Parameters

effort: medium

min_op

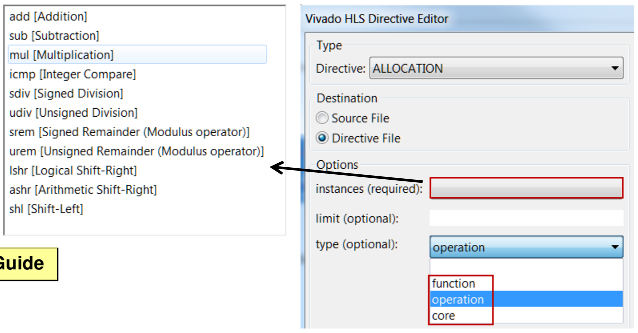
high
medium
low

Allocation: Limit the Numbers

- **Allocation directive limits different types**
  - Type: Operation
    - The instances are the operators
    - Add, mul, urem, etc.
  - Type: Core
    - The instances are the cores

Operators and Cores are listed in the Vivado HLS Library Guide

  - Type: Functions
    - The functions in the code
    - Discussed in more detail later
- **Allocations are defined for a scope**
  - Like all directives, allocations are set for the scope they are applied in
    - If the directive is applied to a function, loop or region, it does not include objects outside that scope



add [Addition]
sub [Subtraction]
mul [Multiplication]
icmp [Integer Compare]
sdiv [Signed Division]
udiv [Unsigned Division]
srem [Signed Remainder (Modulus operator)]
urem [Unsigned Remainder (Modulus operator)]
lshr [Logical Shift-Right]
ashr [Arithmetic Shift-Right]
shl [Shift-Left]

Vivado HLS Directive Editor

Type

Directive: ALLOCATION

Destination

○ Source File
● Directive File

Options

instances (required):

limit (optional):

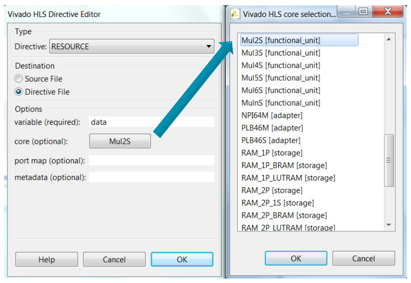
type (optional): operation

function
operation
core

Additional Control: Specify Resources

- **User control of Resources**
  - The resource directive gives user control over the specific resource (core) used to implement operations
    - Select the scope & right-click to apply the directive
    - Select "core" for a list of resources
    - Specify the variable

In this example, "data" is implemented with a 2-stage pipelined multiplier



Vivado HLS Directive Editor

Type
Directive: RESOURCE

Destination
Source File
[✓ Directive File]

Options
variable (required): data
core (optional): Mul2S
port map (optional):
metadata (optional):

Help | Cancel | OK

Vivado HLS core selection...

Mul2S [functional_unit]
Mul3S [functional_unit]
Mul4S [functional_unit]
Mul5S [functional_unit]
Mul6S [functional_unit]
MulnS [functional_unit]
NPI64M [adapter]
PLB46M [adapter]
PLB46S [adapter]
RAM_1P [storage]
RAM_1P_BRAM [storage]
RAM_1P_LUTRAM [storage]
RAM_2P [storage]
RAM_2P_1S [storage]
RAM_2P_BRAM [storage]
RAM_2P_LUTRAM [storage]

OK | Cancel

- **Multiple line coding caveat**
  - If multiple operations occur on a single line
  - A temporary variable is required to isolate the specific operation

```
a=b*c*d
```

```
data= c*d;
a = b*data;
```

XILINX ALL PROGRAMMABLE.

Outline

- Optimizing Resource Utilization
- ***Reducing Area Usage***
- Summary

XILINX ALL PROGRAMMABLE.

Improving Area/Resource Utilization

- **Control the number of elements**
  - Directives can be used to control scheduling and binding
- **Control the design hierarchy**
  - Like RTL synthesis, removing the hierarchy can help optimize across function and loop boundaries
    - Functions can be inlined
    - Loops can be unrolled
- **Array implementation**
  - Vivado HLS provides directives for combining memories
    - Allowing a single large memory to be used instead of multiple smaller memories
- **Bit-width optimization**
  - Arbitrary precision types ensure correct operator sizing

Review: Functions & RTL Hierarchy

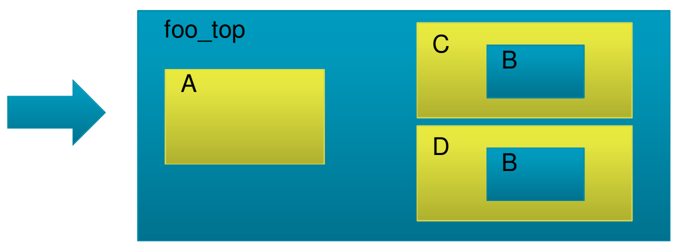
- **Each function is translated into an RTL block**
  - Verilog module, VHDL entity

Source Code

```
void A() { ..body A..}
void B() { ..body B..}
void C() {
                B();
}
void D() {
                B();
}


void foo_top() {
                A(...);
                C(...);
                D(...)
}
```

my_code.c

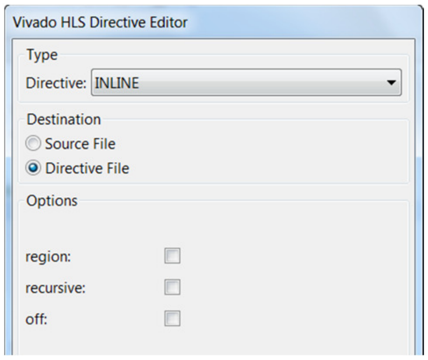
RTL hierarchy



Functions can be inlined – the hierarchy removed & the function dissolved into the surrounding function

Controlling Inlining

- **Vivado HLS performs some inlining automatically**
  - This is performed on small logic functions if Vivado HLS determines area or performance will benefit
- **User Control**
  - Functions can be specifically inlined
    - The function itself is inlined
  - Optionally recursively down the hierarchy
  - Optionally everything within a region can be inlined
    - Everything named region or a function or a loop
  - Optionally inlining can be explicitly prevented
    - Turn inlining off
- **Inlining functions allows for greater optimization**
  - Like ungrouping RTL hierarchies: optimization across boundaries
  - Like ungrouping RTL hierarchies it can result in lots of operations & impact run time


Vivado HLS Directive Editor

Type

Directive: INLINE

Destination

Source File [✓ Directive File]

Options

region: ☐

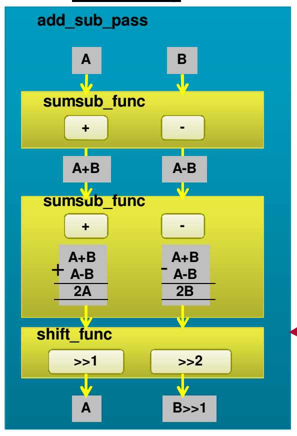
recursive: ☐

off: ☐

Function Inlining

- **Inlining can be used to remove function hierarchy**

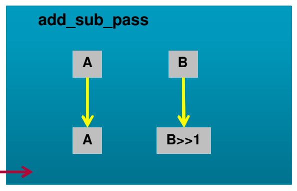
No Inlining



```
int sumsub_func (int *in1, int *in2, int *outSum, int *outSub) {
*outSum = *in1 + *in2;
*outSub = *in1 - *in2;
}

int shift_func (int *in1, int *in2, int *outA, int *outB) {
   *outA = *in1 >> 1;
   *outB = *in2 >> 2;
}

void add_sub_pass(int A, int B, int *C, int *D) {
   int apb, amb;
   int a2, b2;

   sumsub_func(&A,&B,&apb,&amb);
   sumsub_func(&apb,&amb,&a2,&b2);
   shift_func(&a2,&b2,C,D);

}
```

Zero Area

Inlining



2 Adders
2 Subtractors

Inlining allows optimization to be performed across function hierarchies

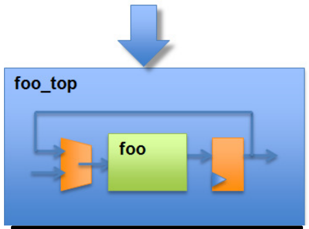
Like RTL ungrouping, too much inlining can create a lot of logic and slow runtime

Inline and Allocation: Shape the Hierarchy

Easy to Share

```
void foo() {

}
void foo_top() {
        foo(...);
        foo(...);
}
```

```
set_directive_allocation -limit 1
    -type function foo_top foo
```

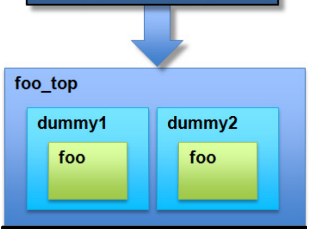


One RTL block is reused for both instances of function *foo*

Cannot be shared

```
void dummy1() {
        foo();
}
void dummy2() {
        foo();
}
void foo_top() {
        dummy1(...);
        dummy2(...);
}
```

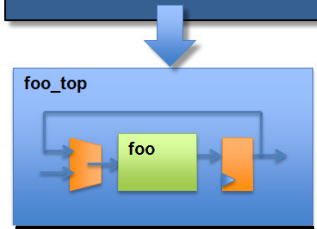
```
set_directive_allocation -limit 1
    -type function foo_top foo
```



Function *foo* is not within the immediate scope of *foo_top*

Controlling Sharing

```
set_directive_allocation -limit 1
    -type function foo_top foo

set_directive_inline dummy1
set_directive_inline dummy2
```

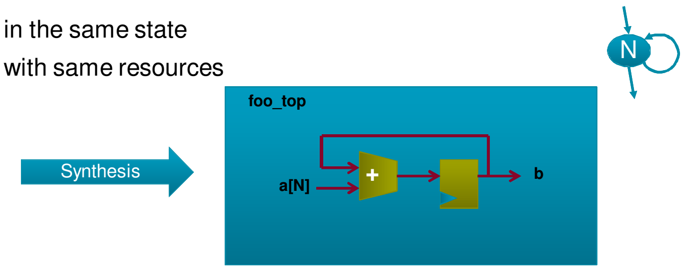


Inlining brings *foo* into function foo_top where it can be shared

Loops

- **By default, loops are rolled**
  - Each C loop iteration ➔ Implemented in the same state
  - Each C loop iteration ➔ Implemented with same resources

```
void foo_top (…) {
  ...
  Add: for (i=3;i>=0;i--) {
           b = a[i] + b;
  ...
  }
```



- **For Area optimization**

Keeping loops rolled maximizes sharing across loop iterations: each <u>iteration</u> of the loop uses the same hardware resources

Loop Merging & Flattening

- **Loop merging & flattening can remove the redundant computation among multiple (related) loops**
  - Improving area (and sometimes performance)

```
My_Region: {
#pragma HLS merge loop
for (i = 0; i < N; ++i)
    A[i] = B[i] + 1;
for (i = 0; i < N; ++i)
    C[i] = A[i] / 2;
}
```

Merge

```
for (i = 0; i < N; ++i) {
    A[i] = B[i] + 1;
    C[i] = A[i] / 2;
}
```

Effective code after compiler transformation

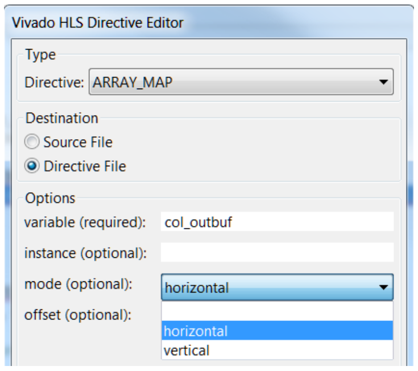
- **Allows Vivado HLS to perform optimizations**
  - Optimization cannot occur across loop boundaries

```
for (i = 0; i < N; ++i)
    C[i] = (B[i] + 1) / 2;
```

Removes A[i], any address logic and any potential memory accesses

Mapping Arrays

- **The arrays in the C model may not be ideal for the available RAMs**
  - The code may have many small arrays
  - The array may not utilize the RAMs very well
- **Array Mapping**
  - Mapping combines smaller arrays into larger arrays
    - Allows arrays to be reconfigured without code edits
  - Specify the array variable to be mapped
  - Give all arrays to be combined the same instance name
- **Vivado HLS provides options as to the type of mapping**
  - Combine the arrays without impacting performance
    - Vertical & Horizontal mapping
- **Global Arrays**
  - When a global array is mapped all arrays involved are promoted to global
  - When arrays are in different functions, the target becomes global
- **Arrays which are function arguments**
  - All must be part of the same function interface


Vivado HLS Directive Editor

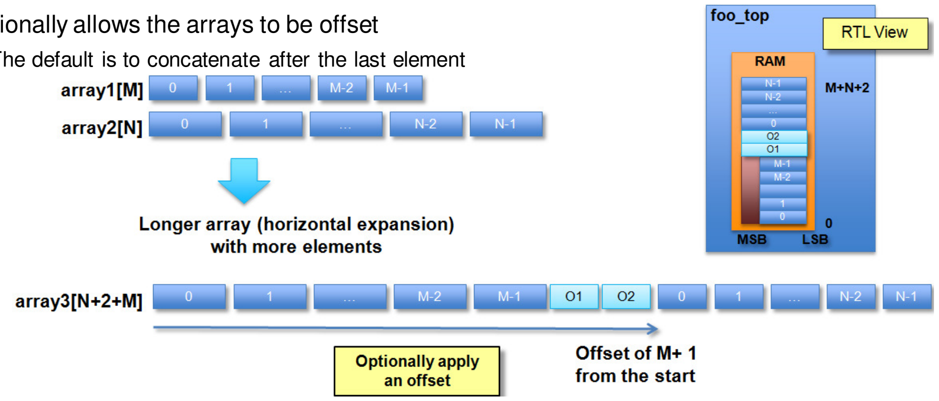
Type
Directive: ARRAY_MAP

Destination
Source File
[✓ Directive File]

Options
variable (required): col_outbuf
instance (optional):
mode (optional): horizontal
offset (optional):
horizontal
vertical

Horizontal Mapping

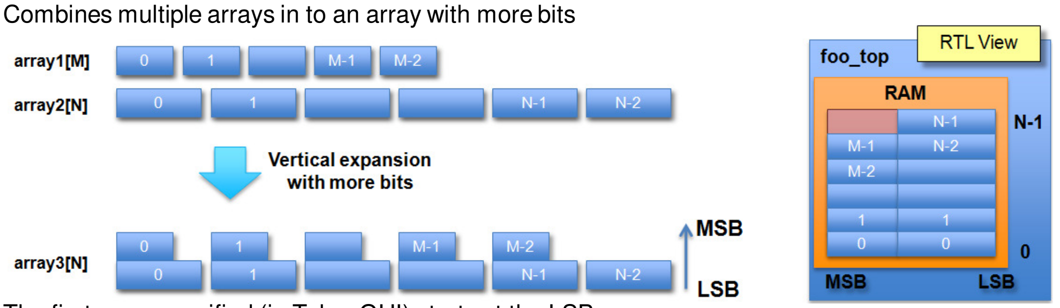
- **Horizontal Mapping**
  - Combines multiple arrays into longer (horizontal) array
  - Optionally allows the arrays to be offset
    - The default is to concatenate after the last element



- The first array specified (in GUI or Tcl script) starts at location zero

Vertical Mapping

- **Vertical Mapping**
  - Combines multiple arrays in to an array with more bits



  - The first array specified (in Tcl or GUI) starts at the LSB
- **Vertical Mapping for performance**
  - Creates RAMs with wide words ➔ Parallel accesses

Arbitrary Precision Integers

- **C and C++ have standard types created on the 8-bit boundary**
  - char (8-bit), short (16-bit), int (32-bit), long long (64-bit)
    - Also provides stdint.h (for C), and stdint.h and cstdint (for C++)
    - Types: int8_t, uint16_t, uint32_t, int_64_t etc.
  - They result in hardware which is not bit-accurate and can give sub-standard QoR
- **Vivado HLS provides bit-accurate types in both C and C++**
  - Plus SystemC types can be used in C++
  - Allow any arbitrary bit-width to be specified
  - Will simulate with bit-accuracy

my_code.c

```
#include ap_cint.h

void foo_top (…) {

   int1          var1;        // 1-bit
   uint1         var1u;       // 1-bit unsigned
   int2          var2;        // 2-bit
   …             …
   int1024       var1024;    // 1024-bit
   uint1024      var1024;    // 1024-bit unsigned

   …
```

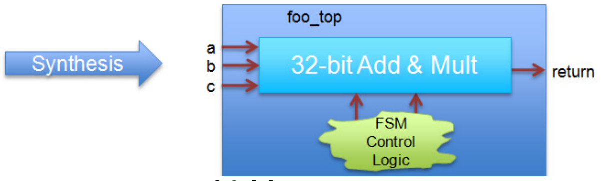
my_code.cpp

```
#include ap_int.h

void foo_top (…) {

   ap_int<1>         var1;         // 1-bit
   ap_uint<1>        var1u;        // 1-bit unsigned
   ap_int<2>         var2;         // 2-bit
   …                 …
   ap_int<1024>      var1024;      // 1024-bit
   ap_int<1024>      var1024u;     // 1024-bit unsigned

   …
```

Why are Arbitrary Precision types Needed?

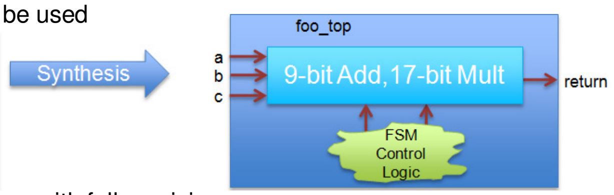
- **Code using native C int type**

```
int foo_top(int a, int b, int c)
{
   int sum, mult;
   sum=a+b;
   mult=sum*c;
   return mult;
}
```



- **However, if the inputs will only have a max range of 8-bit**
  - Arbitrary precision data-types should be used

```
int17 foo_top(int8 a, int8 b, int8 c)
{
   int9 sum;
   int17 mult
   sum=a+b;
   mult=sum*c;
   return mult;
}
```



  - It will result in smaller & faster hardware with full precision

Outline

- Optimizing Resource Utilization
- Reducing Area Usage
- *Summary*

Summary

- **Resource utilization can be reduced using allocation and binding controls**
- **Arbitrary precision data types help controlling both the area and resource utilization**
- **The design structure can be controlled by**
  - Inlining functions: direct impact on RTL hierarchy & optimization possibilities
  - Loops: direct impact on reuse of resources
  - Arrays: direct impact on the RAM
- **Major area optimization techniques**
  - Minimize bit widths
  - Map smaller arrays into larger arrays
    - Make better use of existing RAMs
  - Control loop hierarchy
  - Control function call hierarchy
  - Control the number of operators and cores