POLITECNICO DI MILANO

Compiler Based Optimizations, Tuning and Customization of Generated Accelerators

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Marco Lattuada

Politecnico di Milano
Dipartimento di Elettronica, Informazione e Bioingegneria
marco.lattuada@polimi.it

Outline

- Integration of generated accelerators
- Tuning accelerators by means of optimizations
- Math support

Reset types and values

- Internal status of accelerators can be reset
  - Accelerators expose a reset signal
- Register reset type:
  - no (default)
  - async
  - sync
- Reset level:
  - low (default)
  - high
- Example:

```
--reset-type=sync –reset-level=high
```

Registered inputs

- A dedicated port is created for scalar parameters of each module function
- Generated modules expect stable inputs
  - If inputs are not stable, they must be registered
- Registered inputs:
  - auto (default) – inputs are registered only for shared functions
  - yes
  - no

```
--registered-inputs=<value>
```

FSM-encoding

- Different types of encoding can be used in Finite State Machine
  - one-hot
  - binary
- Default: best encoding for logic synthesis tool
  - Vivado: one-hot
  - Other tools: binary

```
--fsm-encoding=<value>
```

Improve Area/Performance of generated accelerators

- Performance and/or area of the generated accelerators can be improved by tuning the design flow
  - GCC optimizations
  - Bambu IR optimizations
  - Bambu HLS algorithms
- There is no one-fits-all solution
  - Trade off between area and performance
  - Optimizations can have a different impact on each given accelerator
- Default:
  - Balanced area/performance trade off

Translation flow

- C→HDL without optimizations
  - GCC optimizations are (mostly) disabled
  - Bambu IR optimizations are (mostly) disabled

```
-O0 --cfg-max-transformations=0 --no-chaining
```

- Can be used only when bambu is compiled with development support
- Useful for debugging

GCC Optimizations

- Only GCC target-independent optimizations are considered
- -O3 is not necessarily the best choice
  - Can improve performance
  - Can increment area
- User can fine-tune this part of the flow:
  - Selecting the optimization level:

    ```
    -O0 or -O1 or -O2 or -O3 or -Os
    ```

  - Enabling/disabling specific GCC optimizations:

    ```
    -f<optimization> -fno-<optimization>
    ```

  - Tuning gcc parameters: --param

    ```
    --param <name>=<value>
    ```

Effect of GCC Optimizations

- Results are generated with other Bambu options set to the respective default values

Opts	Cycles	Luts
O0	15764	11675
O1	7892	11052
O2	4679	10276
O3	3854	15679
O3 vectorize	3816	38553
O3 all inline	1327	13550

Bambu IR Analysis

- Collect information used by IR optimizations and High Level Synthesis
- Data flow analysis
  - Scalar: based on SSA
  - Aggregates: exploit GCC+Bambu alias analysis
- Graphs Computation
  - Call Graph, CFG, DFG, …
- Loops identification
- Bit Value Analysis
  - Compute for each SSA which bits are used and which bits are fixed

Bambu IR Optimizations

- Applied to the IR produced by GCC (before HLS)
- Available optimizations
  - Single-instruction optimizations
  - Multiple-instruction optimizations
  - Restructuring of Control Flow Graph
  - Fixing IR
- Sequences of optimizations can be applied multiple times
  - Fixed-point iteration optimization flow

Single-Instruction Optimization

- IR lowering makes single instructions more suitable to be implemented in hardware
  - Expansion of multiplication by constant
  - Expansion of division by constant
  - Etc.
- Bit Value Optimization
  - Shrink operations to the only significant bits

Multiple-Instruction Optimization

- Common Subexpression Elimination
- Dead Code Elimination
- Extract pattern (e.g., three-input sum)
- LUT transformations
  - Merging multiple Boolean operations into a single LUT-based operation
- Cond Expr Restructuring

Restructuring of Control Flow Graph

- Speculation
- Code motion
- Merging of conditional branches
  - Creation of a single, multiple-target branch
- Basic Block Removal
  - Empty
  - Last

System of Difference Constraints

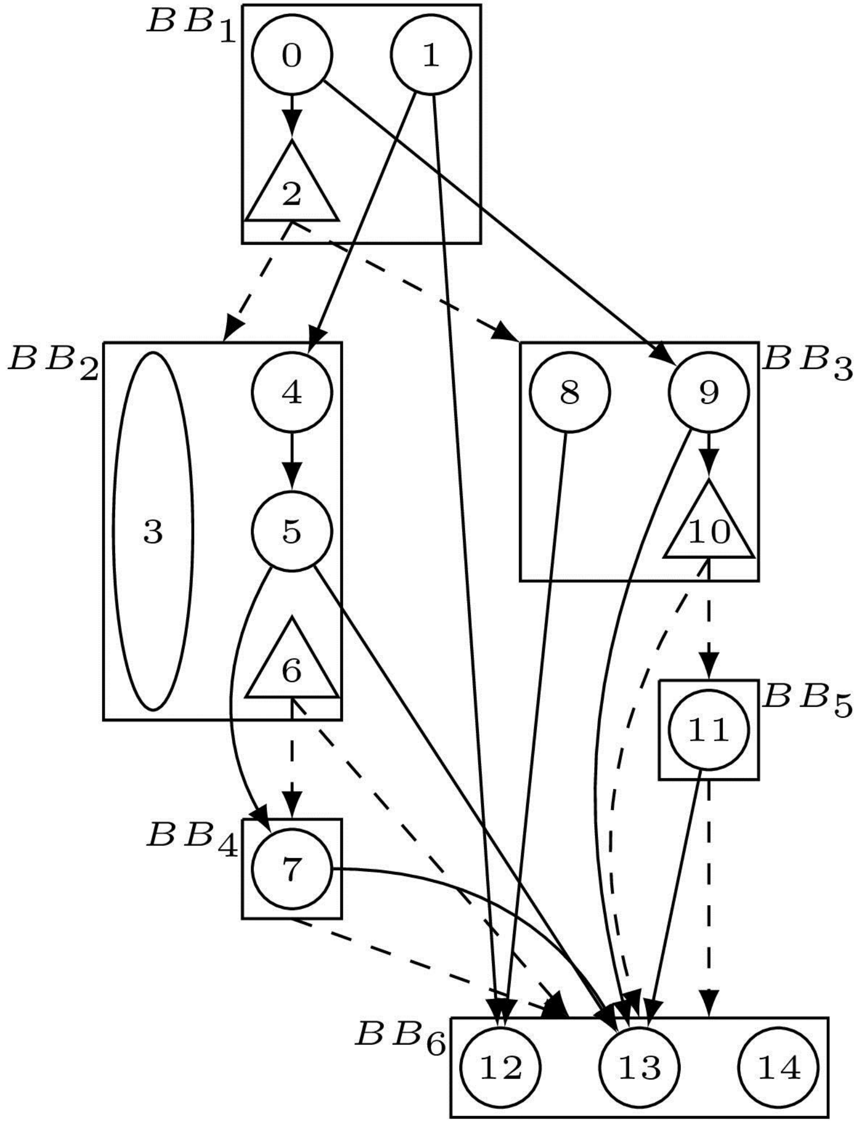
- Global scheduling based on ILP formulation
- Results are used to perform
  - Speculation
  - Code Motion

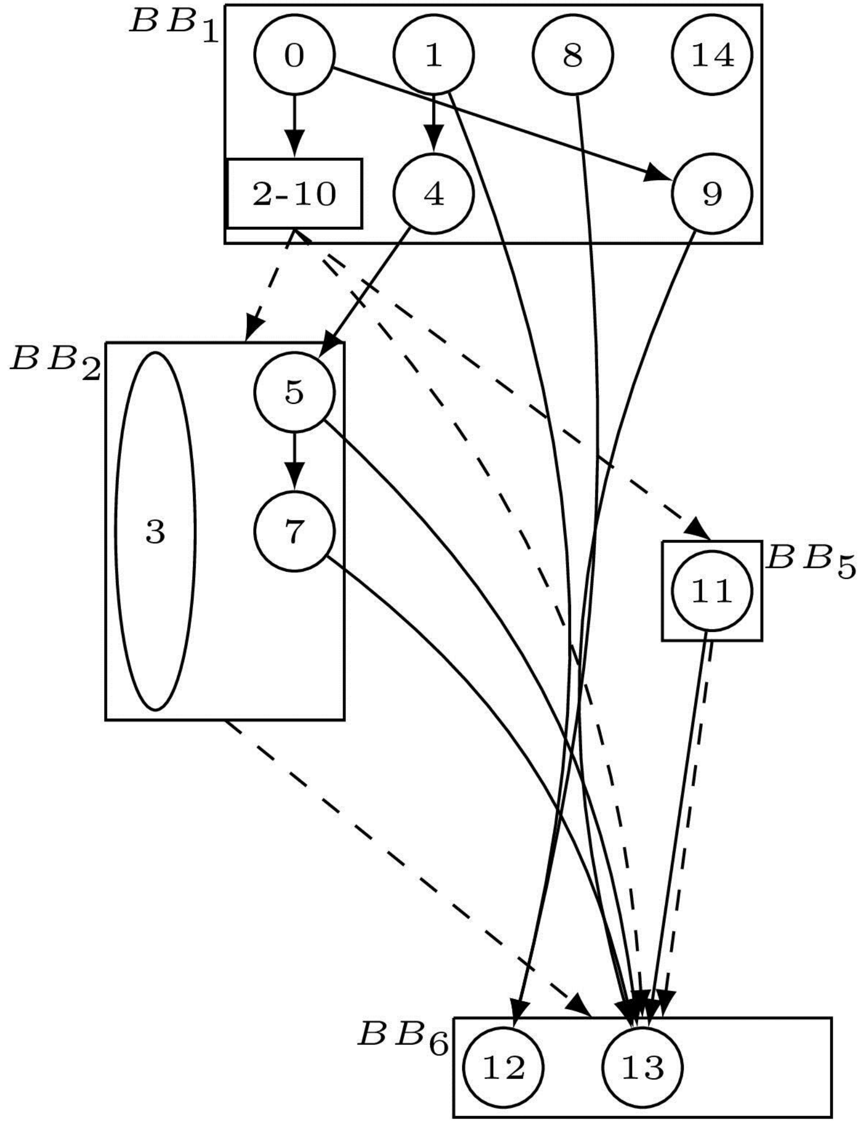
+ Improve performance of accelerators

- Potentially increment area of accelerators

- Increase High-Level Synthesis time

IR optimizations: Example





Fixing IR

- Struct assignment
  - Replaced with memcpy call
- Floating point operations
  - Replaced with function calls
- Integer divisions
  - Replaced with function calls

Experimental setup

- Predefined design flows

```
--experimental-setup=<setup>
```

BAMBU-AREA: optimized for area

BAMBU-PERFORMANCE: optimized for performance

BAMBU-BALANCED: optimized for trade-off area/performance

BAMBU-AREA-MP, BAMBU-PERFORMANCE-MP, BAMBU-BALANCED-MP: enable support for true dual-port memories

Default: BAMBU-BALANCED-MP

Constraints

- Bambu assumes infinite resources during High Level Synthesis
  - Generated solutions may not fit into the target device
- Area can be indirectly controlled through synthesis constraints
  - User can constraint the number of available functional units in each function (e.g., the number of available multipliers)

- Constraints are specified with an *XML file*

Example of constraints file


```
<?xml version="1.0"?>
  <constraints>
    <HLS_constraints>
      <tech_constraints fu_name="mult_expr_FU"
                        fu_library="STD_FU" n="8"/>
    </HLS_constraints>
  </constraints>
```

Integer Division Algorithms

- You can control how to implement integer divisions:

```
--hls-div=<implementation>
```

- Available implementations:
  - `none`: HDL based pipeline restoring division
  - **`nr1`** (default): C-based non-restoring division with unrolling factor equal to 1
  - `nr2`: C-based non-restoring division with unrolling factor equal to 2
  - `NR`: C-based Newton-Raphson division
  - `as`: C-based align divisor shift divident method

Floating point support

- Possible ways of implementing floating point ops:
  - Softfloat (default): customized faithfully rounded (nearest even) version of soft based implementation

    `--soft-float`
  - Softfloat-subnormal: soft based implementation with support to subnormal

    `--softfloat-subnormal`
  - Softfloat GCC: GCC soft based implementation

    `--soft-fp`
  - Flopoco generated modules

    `--flopoco`

Libm versions

- Bambu exploits High Level Synthesis to generate accelerators implementing libm functions
- Two different versions of libm are available
  1. Faithfully rounding (default)
  2. Classical libm built integrating existing libm source code from glibc, newlib, uclibc and musl libraries.
     - Worse performance and area

First example – Evaluate GCC optimizations

- Evaluate the effects of GCC optimizations on the number of cycles of adpcm benchmark
  - Different level of optimizations
  - Vectorization
  - Different inlining

- aes from CHStone suite
  - Yuko Hara, Hiroyuki Tomiyama, Shinya Honda and Hiroaki Takada, "Proposal and Quantitative Analysis of the CHStone Benchmark Program Suite for Practical C-based High-level Synthesis", *Journal of Information Processing*, Vol. 17, pp.242-254, (2009).
- Target device: xc7z020-1clg484-VVD (Zynq with Vivado)
- Target clock period: 10 ns

Solution Hint


```
bambu adpcm.c -O0 --simulate
```

Solution


```
bambu adpcm.c -O0 --simulate

bambu adpcm.c -O1 --simulate

bambu adpcm.c -O2 --simulate

bambu adpcm.c -O3 --simulate

bambu adpcm.c -O3 --simulate
-finline-limit=1000000

bambu adpcm.c -O3 --simulate -ftree-vectorize
```

Second example – Use SDC Scheduling

- Check if SDC scheduling based optimizations further improve the best results obtained in the previous activity

Solution Hint


```
--speculative-sdc-scheduling
```

Solution


```
bambu adpcm.c -O3 --simulate
--speculative-sdc-scheduling
-finline-limit=1000000
```

Third example – Integer Division

- Evaluate the effects on the number of cycles when using different integer division implementations on the dfdiv algorithm targeting Zynq at 66MHz

- dfdiv from CHStone suite
  - Yuko Hara, Hiroyuki Tomiyama, Shinya Honda and Hiroaki Takada,
    "Proposal and Quantitative Analysis of the CHStone Benchmark Program Suite for Practical C-based High-level Synthesis",
    Journal of Information Processing, Vol. 17, pp.242-254, (2009).

Solution Hint


```
--hls-div=<type>
```

Solution

Fourth example– Softfloat and libm

- Generate the module implementing the following equation (single precision and double precision):

$$\gamma = \operatorname{acos}\frac{a^2 + b^2 - c^2}{2ab}$$

- Identify the combination of softfloat ops and libm which produces the best performance

Hint

Use the following parameters:

```
--libm-std-rounding
--soft-float
```

…

Solution

- `--softfloat` is the best choice
- Using of standard or faithful rounding only impacts the area
- Replacing `pow(x, 2.0)` with `x * x` does not improve performance
  - Transformation is already performed by GCC