Creating An Agile Hardware Flow

Stanford AHA! Agile Hardware Center

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How hardware design is done today

Study APP and DSE

Design hardware

Write software
How hardware design is done today

- Study APP and DSE
- Design hardware
- Write software

Verilog, VHDL, SystemVerilog...
How hardware design is done today

Study APP and DSE

Design hardware

Write software
We have a linear staged design flow:

1. create a specification,
2. hardware design,
3. software design.

Problems:

- Change of application requirements.
- Incomplete knowledge/understanding of the problem.
Is there an agile approach to hardware design?
Requirements of an agile hardware/software design approach

- An end-to-end system supporting continuous integration/deployment
  - From applications to a running hardware/software system.
- Evolve that system to make it more efficient.
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Evolving software applications

- With a fixed hardware, we can continuously optimize the applications
- And the compiler.
- Problem: we don’t have fixed hardware when designing accelerators in an agile approach.
Design space exploration

- If we have a fixed set of applications.
- Extract key application parameters.
- Problem: applications and compilers are always changing to be more performant.
A new agile hardware/software design: stable interface
A new agile hardware/software design: CGRA

Coarse-Grain Reconfigurable Architecture (CGRA).
Jade: Our first generation of CGRA

1. Finished in a year with a group of grad students.
2. Built with Genesis2, a hardware generation framework that uses Perl to meta-program hardware modules written in SystemVerilog.
3. Taped out in Summer 2018 and we received packaged parts in January.

<table>
<thead>
<tr>
<th>CGRA Programming Toolchain</th>
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<tr>
<td>Application in Halide</td>
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<tr>
<td>Halide Compiler</td>
</tr>
<tr>
<td>CoreIR Graph</td>
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<tr>
<td>Mapper</td>
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<tr>
<td>Place and Route</td>
</tr>
<tr>
<td>Configuration Bitstream</td>
</tr>
<tr>
<td>Configured CGRA</td>
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Problem: changes affect many tools

New Application comes and we need to change the PE
assign mode = config_mem[1:0];
assign tile_en = config_mem[2];
assign depth = config_mem[15:3];
assign almost_count = config_mem[19:16];
assign enable_chain = config_mem[19];

// ... 216 lines later ...

//;my $filename = "MEM".$self->mname();
//;open(MEMINFO, ">$filename") or die "Couldn't open file $filename, $!";
//;print MEMINFO " <mode bith='1' bitl='0'>00</mode>\n";
//;print MEMINFO " <tile_en bith='2' bitl='2'>0</tile_en>\n";
//;print MEMINFO " <depth bith='16' bitl='3'>0</depth>\n";
//;print MEMINFO " <almost_count bith='19' bitl='16'>0</almost_count>\n";
//;print MEMINFO " <chain_enable bith='20' bitl='20'>0</chain_enable>\n";
//;close MEMINFO;

memory_core.vp
Why choose DSLs

- We want generators to be the spec of a design that produce both RTL and a consistent API for downstream tools to query. This is the single source of truth.

- Generating arbitrary hardware from arbitrary higher-level specifications is an extremely difficult problem.

- Dividing the problem into generating specific types of hardware, such as ALU and interconnect, makes the problem more tractable.
PEak: DSL for Processing Elements (PEs)

- Python-embedded DSL for describing the ISA and functional model of a PE
- Has precise formal semantics
Multiple interpretations of the same PEAk object

PEAk Program

Python Context
- PEAk Program
- Functional Model

Magma Context
- PEAk Program
- RTL

SMT Context
- PEAk Program
- Symbolic Representation
### Overview of DSL designs in our new tool chain

<table>
<thead>
<tr>
<th>PE</th>
<th>MEM</th>
<th>Interconnect</th>
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<tr>
<td>Peak Program</td>
<td>Lake Program</td>
<td>Canal Program</td>
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<tr>
<td>Peak DSL</td>
<td>Lake DSL</td>
<td>Canal DSL</td>
</tr>
<tr>
<td>PE Mapper</td>
<td>MEM Mapper</td>
<td>MEM Mapper</td>
</tr>
</tbody>
</table>

#### Separation of concerns and stages

- **RTL**
- **Naming convention**

- **Gemstone**
- **PE**
- **MEM**
- **Interconnect**

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Next-generation generators
Due to the requirement of physical design, sometimes we have to change the logical implementation.

Common solution:

- Change how the generator produces RTL.

Result:

- The generator becomes brittle and dependent on a particular technology.
- Changes not re-usable.
Lessons learned: Generate design in stages

- Logical design goes through many “passes” to create the final design.
- Re-usable passes for other designs.

What if we want to change how the global signals are wired during physical design?
**Gemstone** is a structural staged generator that allows multiple passes to change the RTL design.

- Well-defined primitives on circuit objects, such as add/remove ports and instantiate generators/circuits.
- Allows multiple passes to change the RTL and generate non-RTL collateral.
An example pass that changes the fanout global signals into a daisy chain.
**Garnet** is more complex and has more component dependencies than the first generation **Jade** chip.
Putting everything together

Garnet SoC layout diagram

- Re-implemented the entire tool-chain from scratch in 7 months.
- Produced a tape-out ready design.
- Full-sized SoC working in RTL simulation.

Chip Spec:
- 32x16 CGRA Array
- 16-bit integer and BFloat PEs
- 4 MB second-level memory
- ARM Cortex M3 with CoreLink
Future plan

- Use DSE feedback to automatically optimize the design.
- Continuously harden the CGRA design to make it more area and power efficient.
- A Linux-capable SoC design.
- More polished tool-chain flow that tests and evaluates the system all the way through to physical design.
Agile hardware design is possible!

We produced 2 chips with complete software stacks in 2 years and we continue to evolve the hardware and software stack.

1. Clean interface between software and hardware allows both of them to be improved together.

2. DSLs for hardware generators make hardware design more tractable and easier to change.

3. Staged generators allow for a separation of concerns between logical description and physical implementation, making the system more robust to changes.
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All our tools are open sourced at https://github.com/StanfordAHA and we would be happy to collaborate.