Implementing Approximate Computing Techniques by Automatic Code Mutation

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Motivation
The Era of Approximate Computing

- Energy-efficiency, computational speed, low-overhead implementation are paramount concern in digital system design:

**Heavy Processing**
- Big-data;
- High-definition multimedia;

**Performance and Cost**
- Energy Vs. Speed;
- General Vs. Special Purpose;

- has been becoming extremely hard to trade-off such features:
  - Literature is introducing post-Moore’s Law era, non Von Neumann architectures, and so on...
- Even though... a *perfect* result is often not necessary:
  - an approximate of a less-than-optimal result is sufficient;
  - approximation opens the opportunity to deal with tight performance constraints;
Outline

1. Introduction
2. Research Effort
3. IDEA Tool
4. Result
5. Conclusion
Outline for Introduction

1 Introduction
   - Approximate Computing
   - Inherent application resiliency

2 Research Effort

3 IDEA Tool

4 Result

5 Conclusion
Approximate Computing in a Nutshell
Towards the trading performance off for the quality

Rather than the best possible result, approximate computing exploits inaccurate outputs to outperform classical elaboration approaches:
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  - by altering software execution;
  - e.g. loop perforation;
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- Rather than the best possible result, approximate computing exploits inaccurate outputs to outperform classical elaboration approaches:
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    - e.g. loop perforation;
  - by employing inexact custom circuits;
    - e.g. speculative arithmetic operations;
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  - e.g. loop perforation;
- by employing inexact custom circuits;
  - e.g. speculative arithmetic operations;
- by approximately storing data;
  - e.g. DRAM with lower refresh rate.
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Approximate Computing

- Several domains may benefit from approximation:
  - signal processing: image, video, audio, speech;
  - machine learning;
  - data mining;
  - search;
  - ...

- In the past, Approximate Computing was often considered an effect of the "human interpretation":
  - the literature has demonstrated the crucial role of the inherent application resiliency.
The Inherent Application Resiliency is a property for an algorithm to return **acceptable outcomes** despite some of its inner computations being **approximate or imprecise**;

Approximate Computing exploits a design approach that **leverages the inherent resiliency** through optimizations which **trade the outputs quality off for enhanced performance**, such as time, energy consumption, occupied area, and so on;
The property mainly inherits from:

1. Perturbed (Real Inputs)
2. Redundant Input data
3. Iterative algorithms / Self-Healing
4. Stochastic Computations
5. No/Golden Output
6. Perceptual Limitations

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1 Venkataramani, S. et al. Approximate computing and the quest for computing efficiency. 52nd Annual Design Automation Conference
A new design parameter

- Establish how much approximate;
- Trade resources saved off for inaccuracy.

Integration in classical flow

- Algorithms, tools, languages, models . . .
- Ensemble of Approximate Computing techniques.
Outline for Research Effort

1. Introduction

2. Research Effort
   - Approximate Computing Tools and Methodologies

3. IDEA Tool

4. Result

5. Conclusion
Precimonious
Tuning Assistant for Floating-Point Precision

- It is an automatic tuning tool for the IEEE 754 floating point types of C/C++ code by means of annotation that gives the user-desired accuracy;
- It uses the LLVM IR (so it works on compiled codes) to generate and evaluate different configurations using an algorithm based on the delta-debugging;
- The results are in the form of LLVM IR and they must be manually mapped to the original source code, in order to give the actual result to the programmer;
- The search algorithm is based on the delta-debugging with the adoption of an heuristic pruning technique.
Adaptation for C/C++ of EnerJ (from the same authors) which works in the Java environment:

- It aims to help the programmers to approximate their own code, because authors claim automatic approaches loses practicality and controllability;
- It supports the main approximation techniques such as loop perforation or synchronization relaxation;
- It works on the LLVM Intermediate Representation, propagating the source code annotations to manage the real approximation at this level;

To support the new dialect it introduces a new compiler (enerc and enerc++) for the LLVM infrastructure;

- It considers approximation effects which are linear! There is no a proper exploration algorithm.
It extends ACCEPT, using it to *intercept* at LLVM IR level the instructions that has been marked as *approximate*;

This hook mechanism is used to redirect those instructions to *user-defined* approximate techniques that they have implemented to quickly compare their effect;

A simple linear energy model is presented in order to estimate the energy savings available through approximation.
Outline for IDEA Tool

1. Introduction
2. Research Effort
3. IDEA Tool
   - Approximation through Mutation
   - IDEA for loop perforation: a walkthrough
4. Result
5. Conclusion
Available tool and methodologies do not approach Approximate Computing with a general technique:

- dependency to the language target;
- software or hardware;
- handling of only one technique or few variants of one;
- quality/error estimation is not flexible;
- access to the source code or customization of the tool.

We tried to deal with such problems by introducing a new methodology and a corresponding tool:

- The novelty stands in making an algorithm approximate by mutation;
- The whole approach is totally user-defined.
Hypotheses

- The error is directly related to the magnitude of the approximation applied on involved operations;
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- The error cannot be universally defined.
**Towards Automatic Exploration of Variants**

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**Requirements**

- **Tuning** process over every approximable inner operation;
Towards Automatic Exploration of Variants

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Requirements

- *Tuning* process over every approximable inner operation;
- **Customizable** quality function with respect to the original version;
Towards Automatic Exploration of Variants

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- Tuning process over every approximable inner operation;
- Customizable quality function with respect to the original version;
- Controllable amount of error;
Towards Automatic Exploration of Variants

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Requirements

- **Tuning** process over every approximable inner operation;
- **Customizable** quality function with respect to the original version;
- **Controllable** amount of error;
- **Automatic** exploration of approximate configurations.
Approximate C/C++ Algorithms

We have got an IDEA!

- We devised IDEA (IDEAA is a Design Exploration tool for Approximating Algorithms), a novel approach which explores possible inaccuracies that can be applied on an algorithm written in C/C++:
  - IDEA integrates clang-Chimera, which is a source-to-source transformation tool, which can be configured with customizable transformation rules;
  - the generation of approximate mutants is: fully automatic, generic (ideally, IDEA would implement every proposed Approximate Computing technique), and is runnable in software;
- IDEA explores design solutions with a B&B approach:
  - Solutions define inherently a Pareto frontier;
  - They can be used to configure both hardware and software algorithms;
- IDEA tools are open source and can be freely downloaded and extended.
IDEA Flow

Algorithm side

Original Project Files

Mutated Files

Pareto-frontier configurations

Tool flow

clang-Chimera

IDEA side

Operator-1
Operator-2
...

user config

op config

user config

Plug-in 1
Plug-in 2
...

Coding

Mutation

Design Space

Exploration

IDEA Tool

Original Project Files

Plug-in 1
Plug-in 2
...

user config
Clang-Chimera is part of the Chimera Tools, a set of tools for mutating C/C++;
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- It is implemented using the Chimera Design, that is based on the Mutation Template concept, an efficient and flexible way to generate mutants from an abstract syntax tree (AST) representation of the source code;
Clang-Chimera

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  - Free available (GPLv3) at: https://git.io/vKOZK
- It is implemented using the Chimera Design, that is based on the *Mutation Template* concept, an efficient and flexible way to generate mutants from an abstract syntax tree (AST) representation of the source code;
- The idea is to avoid unnecessary AST visits to produce multiple mutants of the same target file, so a *mutation template* can be seen as a “list” of locations on the AST, in which it will be necessary to apply some kind of mutations.
Let us consider two well-known Approximate Computing techniques:

**Loop First**

```c
for(i = 0; i < n; i += stride){
    body
}
```

**Loop Second**

```c
for(i = 0; i < n; i ++){
    if(i % stride != 0)
        body
}
```

- They are defined to *skip* some iterations of a loop, aiming at save time execution worsening the output result;
- Both of them requires the definition of the *stride* value.
In order to define a new mutator (or *operator*), the user needs to *inherit* the mutator class and has to define 3 methods:

1. **getStatementMatcher**: coars-grain match over the AST;
2. **match**: fine-grain match, which prepares variables for mutate;
3. **mutate**: modifies involved AST nodes;

W.r.t. loop perforation, the first method looks for the *forStm* nodes, while the others applies the mutation whenever there are proper initialization and termination conditions.
IDEA has to be configured with proper plug-ins which are able to:

1. handle mutated source files and configurations;
2. modify mutation parameters (e.g. strides), accordingly to the approximate computing technique;

Once the mutators and the plug-ins are defined, the tool-flow is able to explore approximate variants of an arbitrary source code written in C/C++.
In order to mutate a source code, the user has to provide:

1. the source code itself;
2. a configuration file for clang-Chimera reporting target C/C++ functions and the list of operators that have to be applied to the source code;

The output is the mutated source code and a report, which contain the list of mutated files and the operators applied.

IDEA uses this file together with the error/quality function, provided by the user, to evaluate each approximate variant.
Outline for Result

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4. Result
   - Experimental result
5. Conclusion
As last step, we use two algorithms as target of the IDEA flow:

**Taylor series expansion**
- Expansion of function $e^x \cdot \ln(1 + x)$;
- Function evaluated up to the 250 power;
- Error calculated over $10^4$ points as absolute difference with an oracle.

**Inverse Discrete cosine transformation**
- Decompression of 10 gray scale images;
- 8x8 pixels block;
- Error computed as average PSNR between original and decompressed images.
As last step, we use two algorithms as target of the IDEA flow:

- Taylor required the exploration of $10^6$ variants for the LoopFirst and $10^5$ for the LoopSecond.
- IDCT required the exploration of 200 variants for the LoopFirst and 3000 for the LoopSecond.
Focus on the IDCT

Original DCT Compression Vs. IDEA Configuration

- PSNR: 14.637
Outline for Conclusion

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   - Conclusion
### Conclusion and Remarks

- **IDEA** is an extensible Approximate Computing tool as it relies on the concept of the mutation code, performed by clang-Chimera tool:
  - It is able to handle any kind of approximate computing technique;
  - the mutation algorithm is written in C/C++;
  - **IDEA** provides Pareto-solutions that can be use for both hardware and software projects;

- We proved the approach with experimental result and we also demonstrated its feasibility by case studies.
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