Implementing Approximate Computing Techniques by Automatic Code Mutation

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WAPCO 2017, Stockholm, Sweden
January, 25th 2017

DIPARTIMENTO DI INGEGNERIA ELETTRICA E DELLE TECNOLOGIE DELL'INFORMAZIONE
UNIVERSITA' DEGLI STUDI DI NAPOLI FEDERICO II
LIRMM

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;

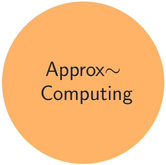
- has been becoming extremely hard to trade-off such features;
  - Literature is introducing post-Moore's Law era, non Von Neumann architectures, and so on...
- Even though... a *perfect* result is often not necessary:
  - an approximate of a less-than-optimal result is sufficient;
  - approximation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

Outline

Outline for Introduction

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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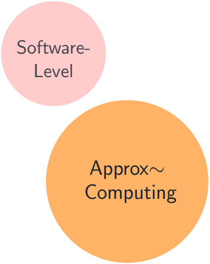

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    - e.g. loop perforation;

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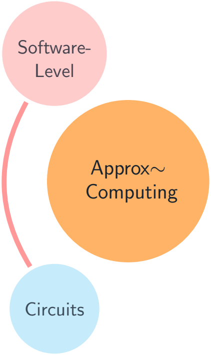

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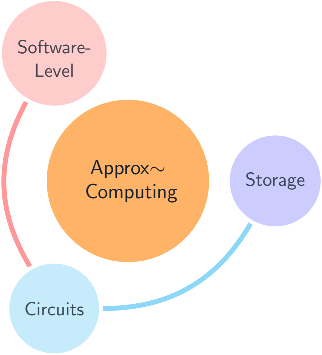

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  - by approximately storing data;
    - e.g. DRAM with lower refresh rate.

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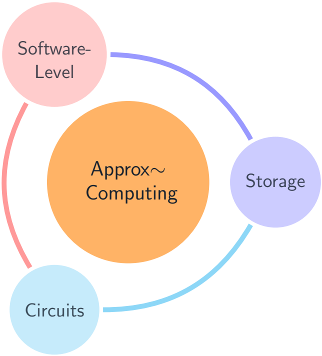

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Approximate Computing

- 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**.

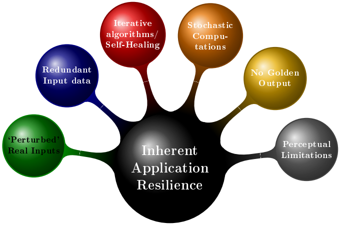
The Inherent Application Resiliency

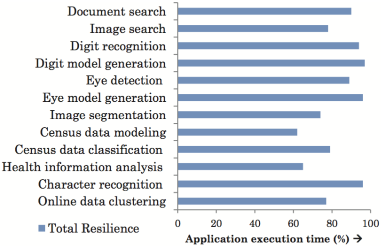
- The Inherent Application Resiliency is a property for an algorithm to return **acceptable outcomes** despite some of its inner computations being **approximate or imprecise**;
- Approximate Computing exploits a design approach that **leverages the inherent resiliency** through optimizations which **trade the outputs quality off for enhanced performance**, such as time, energy consumption, occupied area, and so on;

The Inherent Application Resiliency

Main sources

- The property mainly inherits from:





83% of run time spent in resilient computations

1

[1] Venkataramani, S. et al. Approximate computing and the quest for computing efficiency. 52nd Annual Design Automation Conference

Approximate Design... Possible?

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

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.

ACCEPT

A Programmer-Guided Compiler Framework for Practical Approximate Computing

- 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.

REACT

A Framework for Exploration of Approximate Computing Techniques

- 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

Mutate And Explore

- 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 make an algorithm approximate by mutation;
  - The whole approach is totally user-defined.

Towards Automatic Exploration of Variants

Hypotheses

- The error is directly related to the **magnitude of the approximation** applied on involved operations;

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- *Tuning* process over every approximable inner operation;

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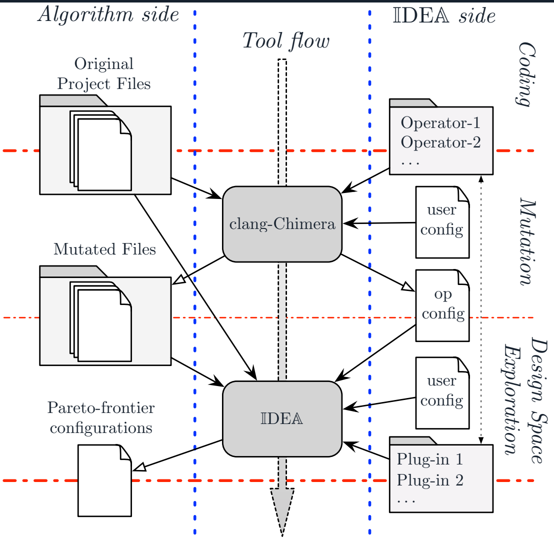
- **Controllable** amount of error;
- **Automatic** exploration of approximate configurations.

Approximate C/C++ Algorithms

We have got an 𝕀DE𝔸!

- We devised 𝕀DE𝔸 (**I**IDEA**A** **I**s a **D**esign **E**xploration tool for **A**pproximating **A**lgorithms), 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 <u>hardware and software</u> algorithms;
- 𝕀DE𝔸 tools are open source and can be freely downloaded and extended.

IDEA Flow


Algorithm side
Tool flow
IDEA side
Coding
Mutation
Design Space Exploration
Original Project Files
Operator-1
Operator-2
...
clang-Chimera
user config
Mutated Files
op config
user config
IDEA
Pareto-frontier configurations
Plug-in 1
Plug-in 2
...

Clang-Chimera

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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;
- 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.

IDEA Supporting Loop-Perforation

- Let us consider two well-known Approximate Computing techniques:

Loop First

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

Loop Second

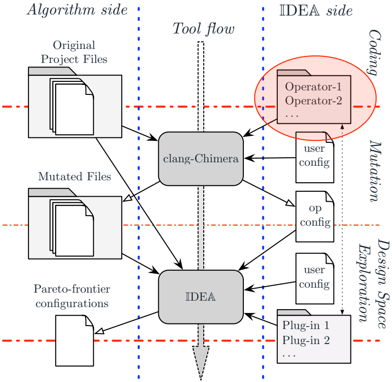
```
for(i = 0; i < n; i ++){
   if(i % stride != 0)
      body
}
```

- 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.

IDEA Supporting Loop-Perforation

Defining Operators in clang-Chimera

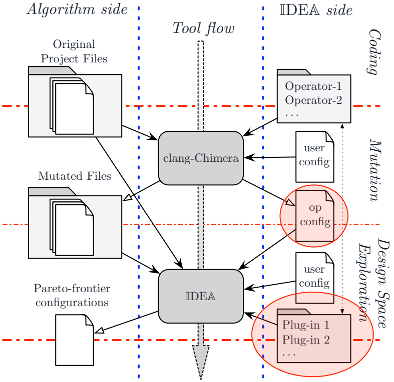
- In order to define a new mutator (or *operator*), the user needs to *inherit* the mutator class and has to define 3 methods:
  1. `getStatementMatcher`: coars-grain match over the AST;
  2. `match`: fine-grain match, which prepares variables for mutate;
  3. `mutate`: modifies involved AST nodes;



- W.r.t. loop performation, the first method looks for the *forStm* nodes, while the others applies the mutation whenever there are proper initialization and termination conditions.

IDEA Supporting Loop-Perforation

Defining IDEA plugins



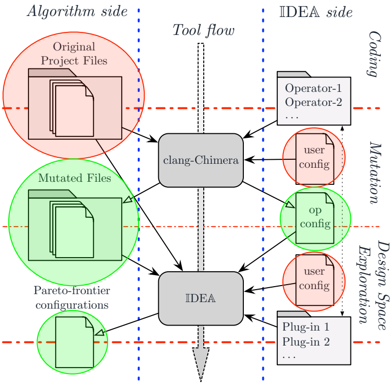
- IDEA has to be configured with proper plug-ins which are able to
  1. handle mutated source files and configurations;
  2. modify mutation parameters (e.g. strides), accordingly to the approximate computing technique;

- 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++.

IDEA Supporting Loop-Perforation

Getting approximate variants

- 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

Loop Perforation

- 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

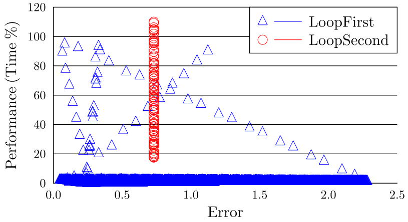
- Decompression of 10 gray scale images;
- 8x8 pixels block;
- Error computed as average PSNR between original and decompressed images.

Loop Perforation

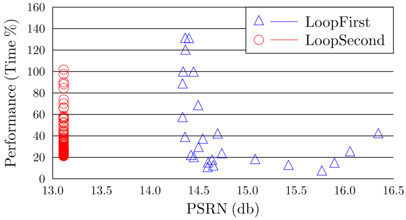
Experimental evidences

- As last step, we use two algorithms as target of the $\mathbb{IDEA}$ 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

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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