Performance Optimization with PerfExpert and MACPO

Jim Browne, Ashay Rane and Leo Fialho

ICS 2013

TACC

THE UNIVERSITY OF TEXAS AT AUSTIN

Agenda

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In the morning:

09:00 Introduction and motivation *[Jim]*

09:20 What PerfExpert can provide to you? *[Leo]*

09:30 Demo *[Leo]*

09:45 How PerfExpert does that? (opening Pandora's box) *[Leo]*

10:15 Extending PerfExpert *[Leo]*

10:30 (Coffee?) break *[everyone, including you]*

10:45 Hands on tutorial *[all the team]*

11:45 Morning closure *[all the team]*

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In the afternoon:

01:30 What MACPO can provide to you? *[Ashay]*

02:00 Demo *[Ashay, Jim]*

02:30 How MACPO does that? *[Ashay]*

03:15 (Coffee?) break *[everyone, including you]*

03:30 Hands on tutorial *[Ashay]*

04:00 Selecting code segments to run on GPUs/accelerators *[Jim]*

04:30 Enhancing PerfExpert with MACPO analysis *[all the team]*

04:45 Afternoon closure and future work *[all the team]*

Overview: why PerfExpert?

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Problem: HPC systems operate far below peak

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Result: Many HPC programmers do not use these tools

(seriously)

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- Performance report only
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Performance report:

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Performance report:

```
Loop in function compute() at mm.c:8 (99.8% of the total runtime)
================================================================================
ratio to total instrns       % 0.........25..........50.........75........100
   - floating point      :   100 ************************************************
   - data accesses       :    25 ************
* GFLOPS (% max)         :    12 ******
   - packed              :     0 *
   - scalar              :    12 ******
--------------------------------------------------------------------------------
performance assessment     LCPI good......okay......fair......poor......bad....
* overall                :   3.0 >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>+
upper bound estimates
* data accesses          :   9.6 >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>+
   - L1d hits            :   0.9 >>>>>>>>>>>>>>>>>
   - L2d hits            :   1.8 >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
   - L2d misses          :   6.9 >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>+
* instruction accesses   :   0.1 >
   - L1i hits            :   0.0 >
   - L2i hits            :   0.0 >
   - L2i misses          :   0.1 >
* data TLB               :   4.6 >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>+
* instruction TLB        :   0.0 >
* branch instructions    :   0.1 >>
   - correctly predicted :   0.1 >>
   - mispredicted        :   0.0 >
* floating-point instr   :   5.1 >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>+
   - fast FP instr       :   5.1 >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>+
   - slow FP instr       :   0.0 >
```

What PerfExpert can provide to you?

List of Recommendations:

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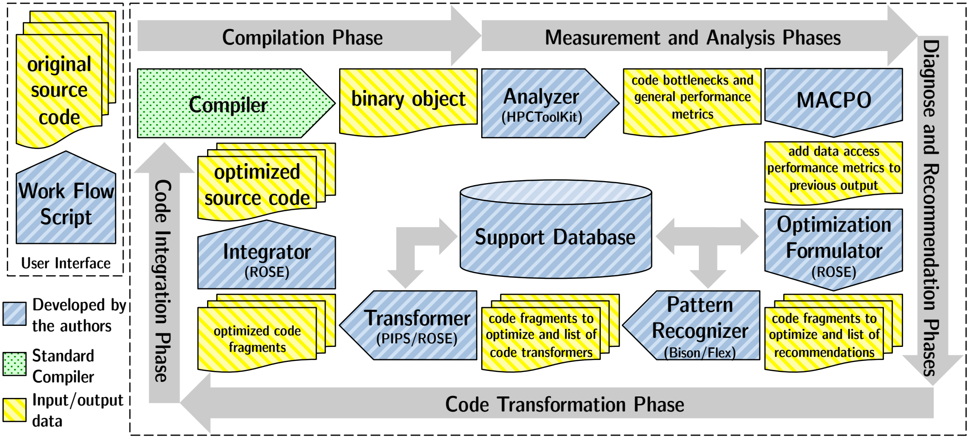
List of Recommendations:

```
#--------------------------------------------------
# Recommendations for mm.c:8
#--------------------------------------------------
#
# This is a possible recommendation for this code segment
#
Recommendation ID: 31
Recommendation Description:  change the order of loops
Recommendation Reason:  this optimization may improve the memory access pattern and make it more
cache and TLB friendly
Pattern Recognizers:  c_loop2 f_loop2
Code example:
loop i {
  loop j {...}
}
=====> loop j {
  loop i {...}
}
```

Short Demo

Short demo

How PerfExpert does that: The Big Picture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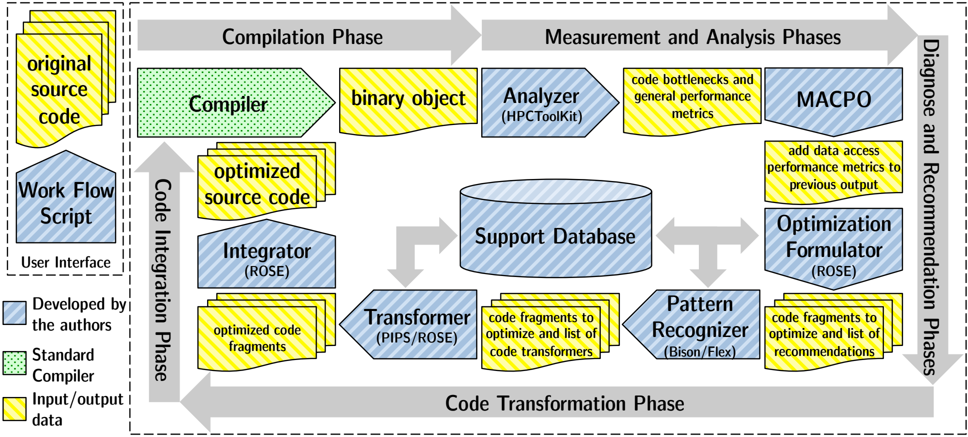
How PerfExpert does that: Work Flow Script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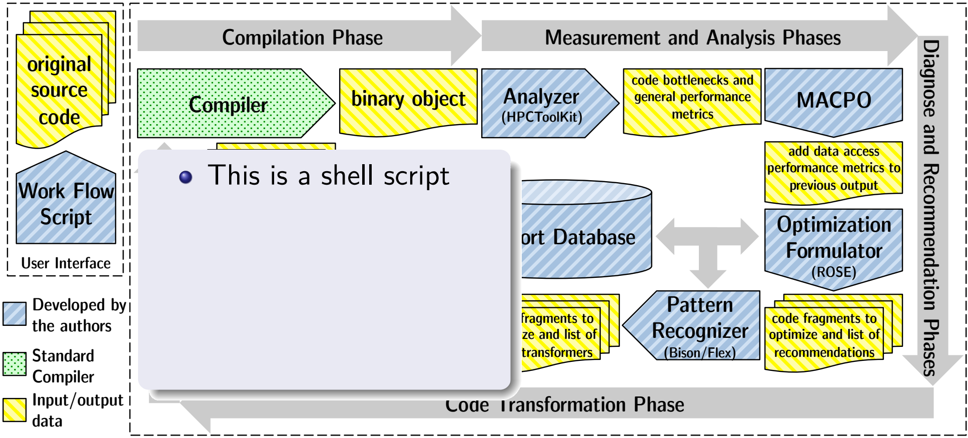
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- This is a shell script

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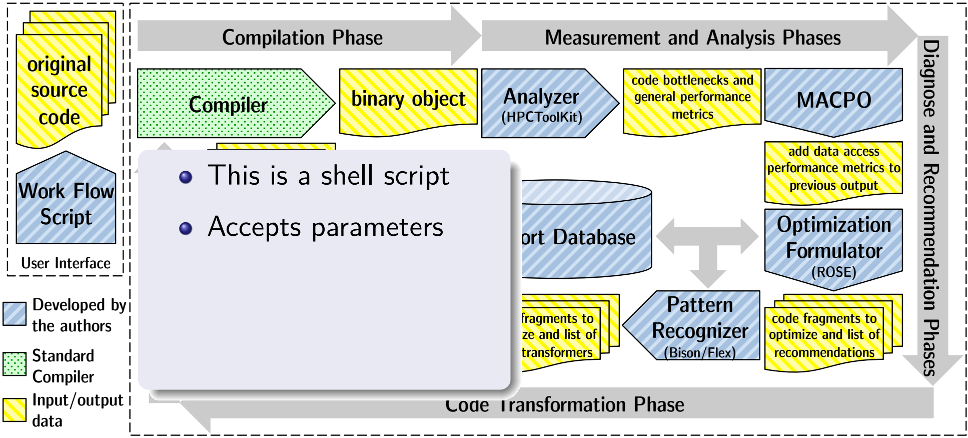
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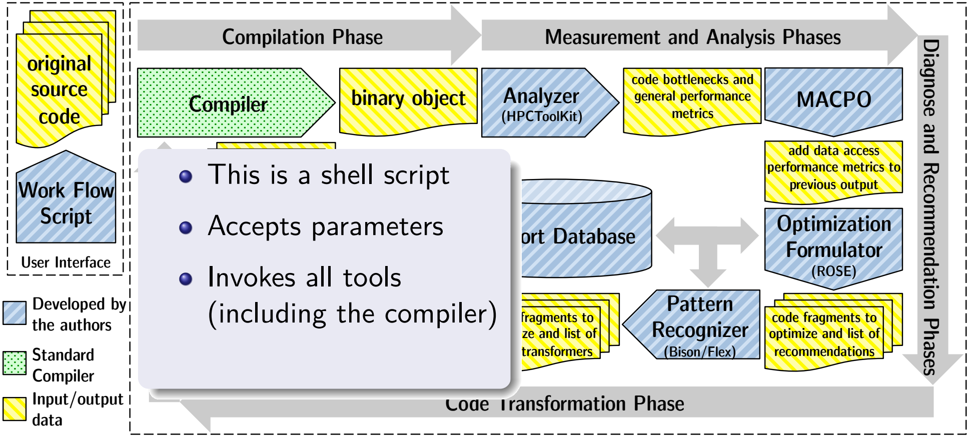
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- Invokes all tools (including the compiler)

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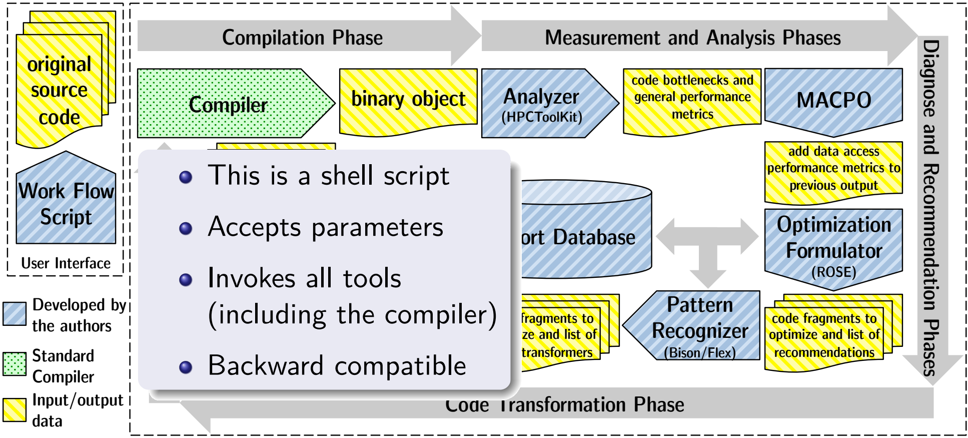
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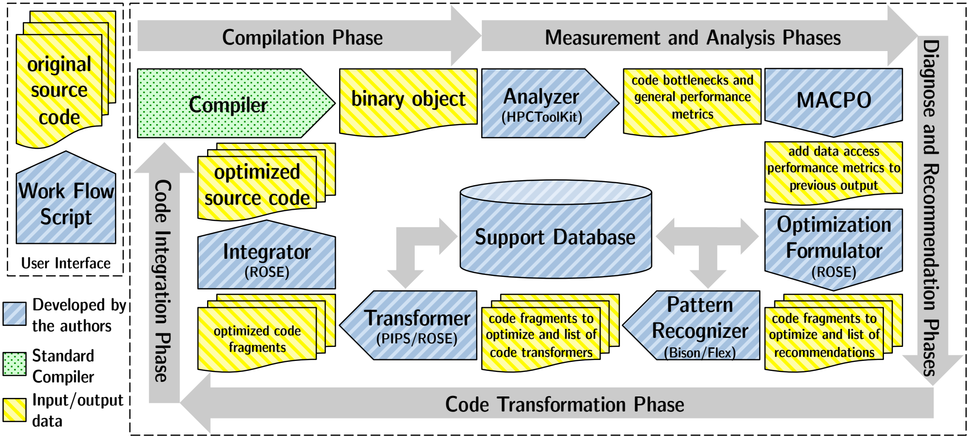
- Backward compatible

How PerfExpert does that: Analyzer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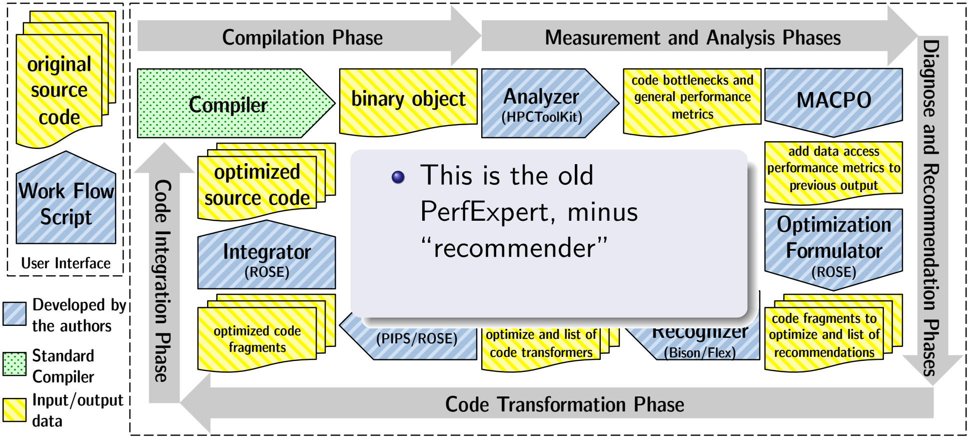
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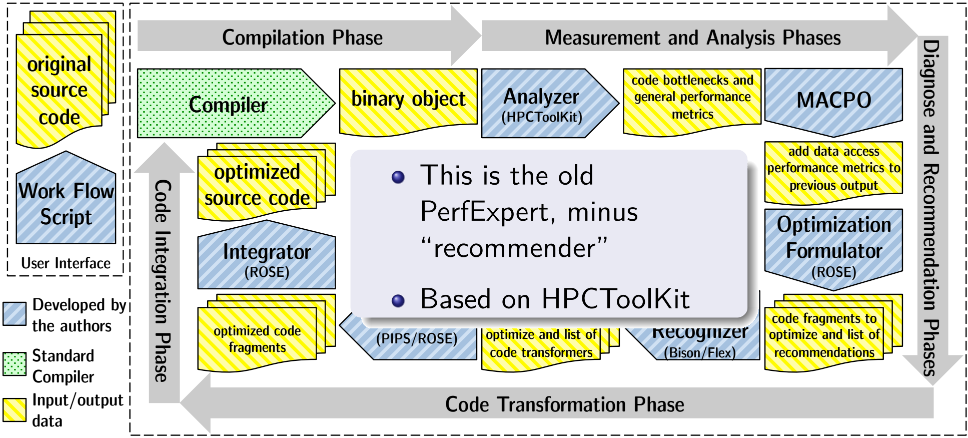
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- Based on HPCToolKit

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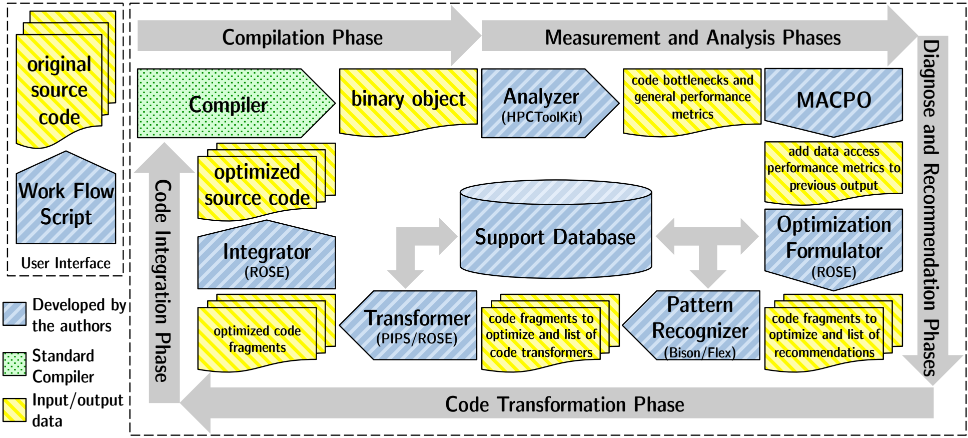
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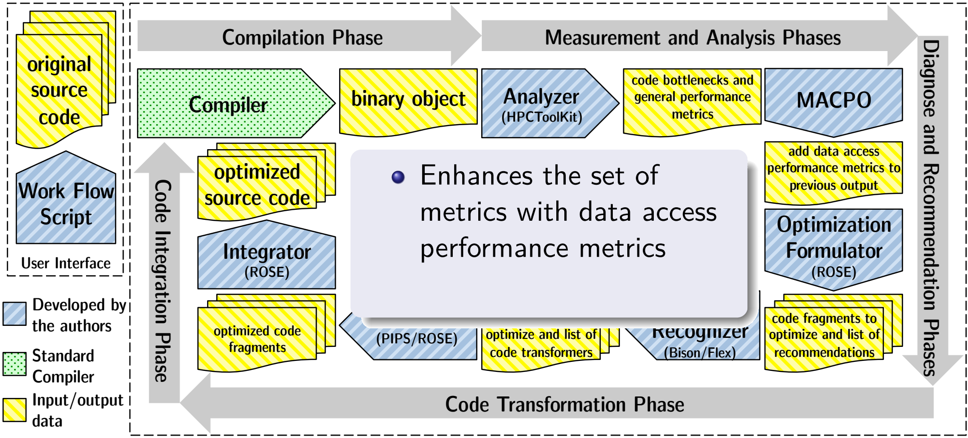
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- Enhances the set of metrics with data access performance metrics

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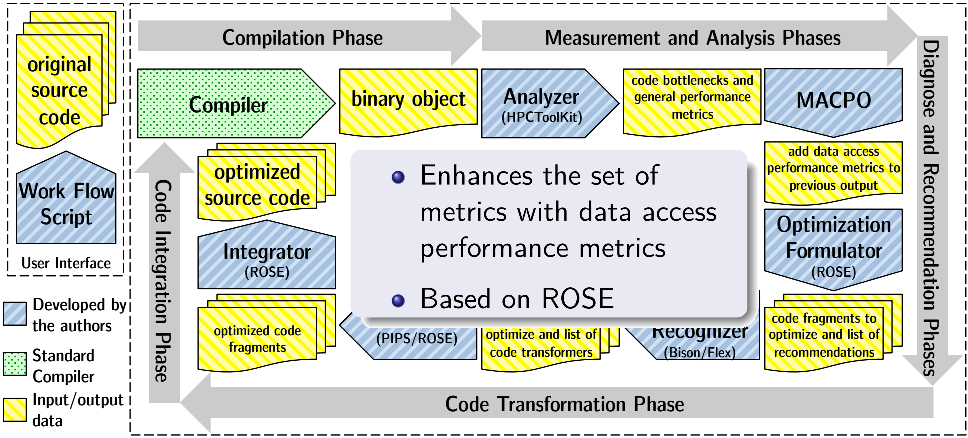
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- Based on ROSE

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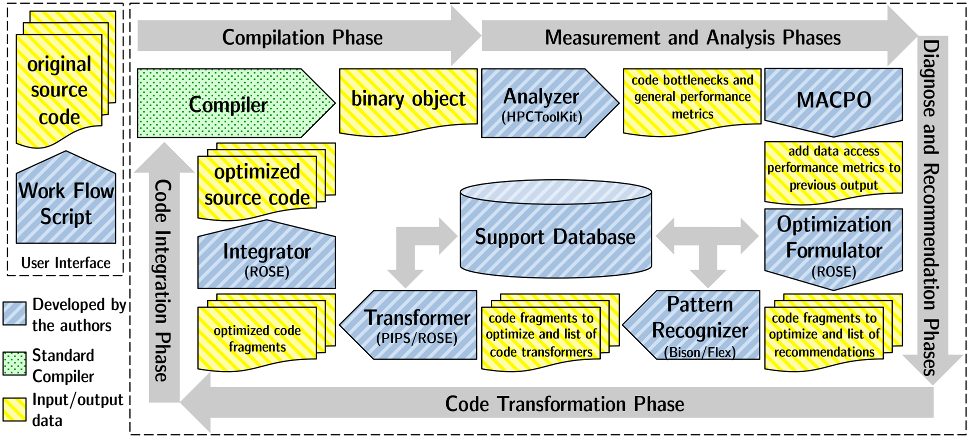
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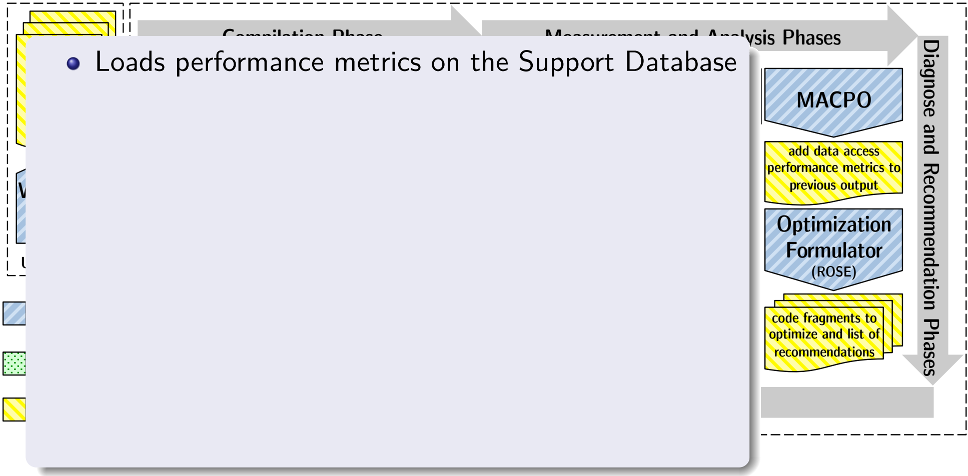

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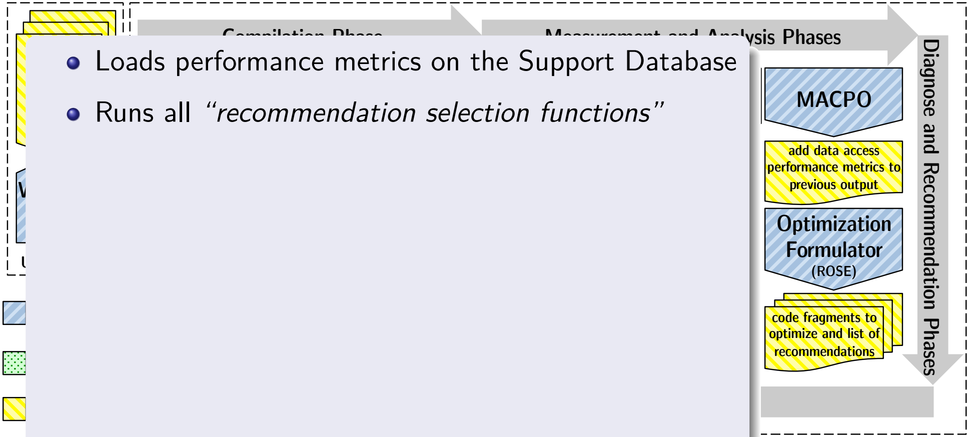
add data access performance metrics to previous output
Optimization Formulator (ROSE)
code fragments to optimize and list of recommendations
Diagnose and Recommendation Phases

- Loads performance metrics on the Support Database

How PerfExpert does that: Optimization Formulator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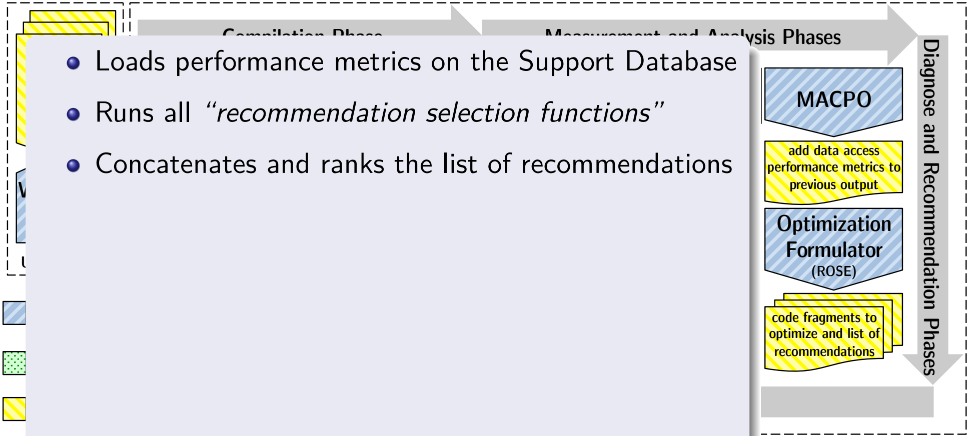
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How PerfExpert does that: Optimization Formulator

- Loads performance metrics on the Support Database
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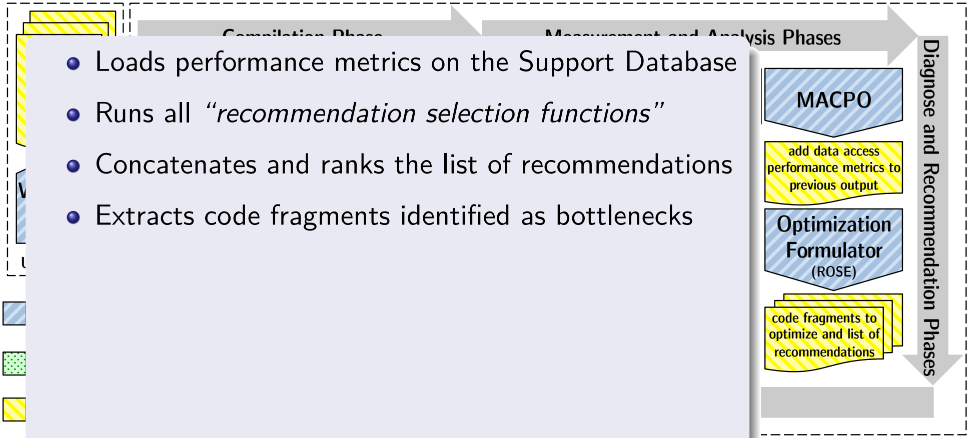
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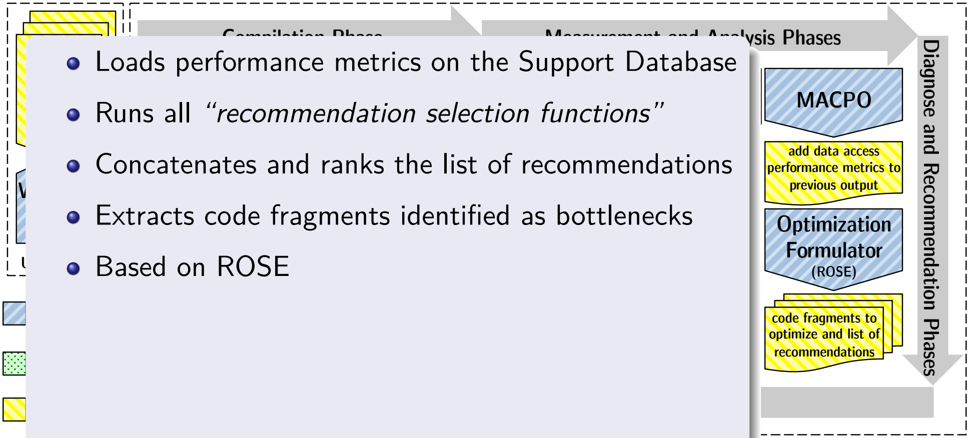
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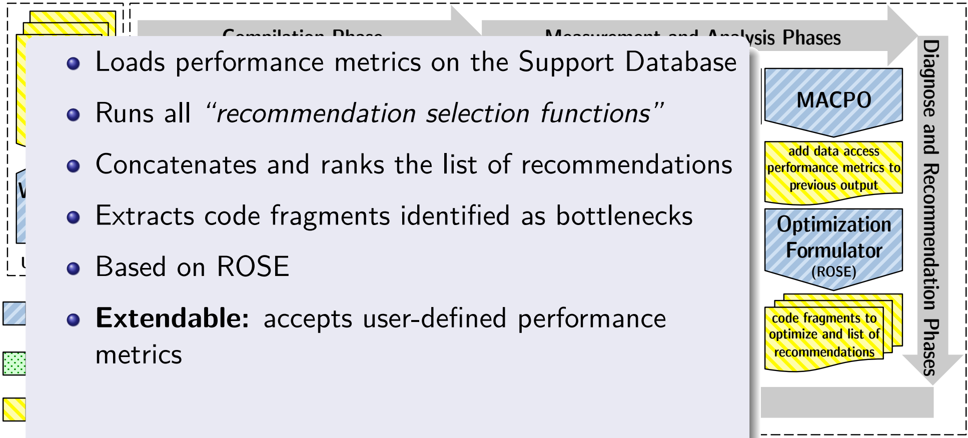
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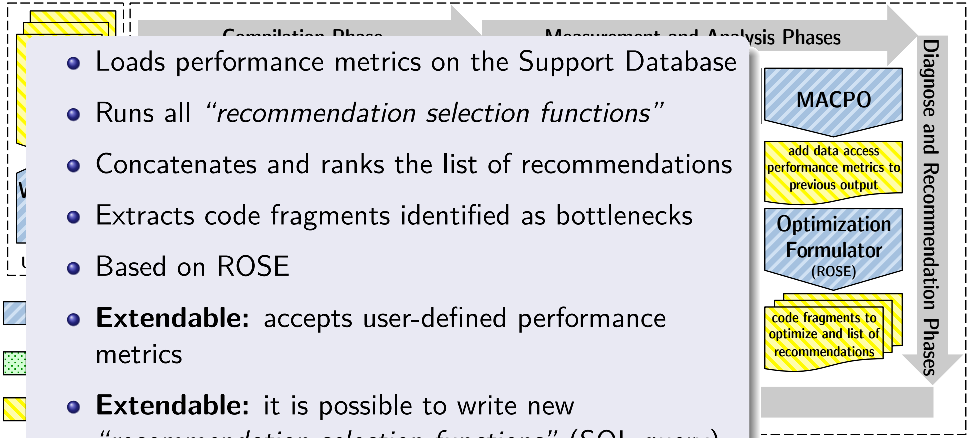
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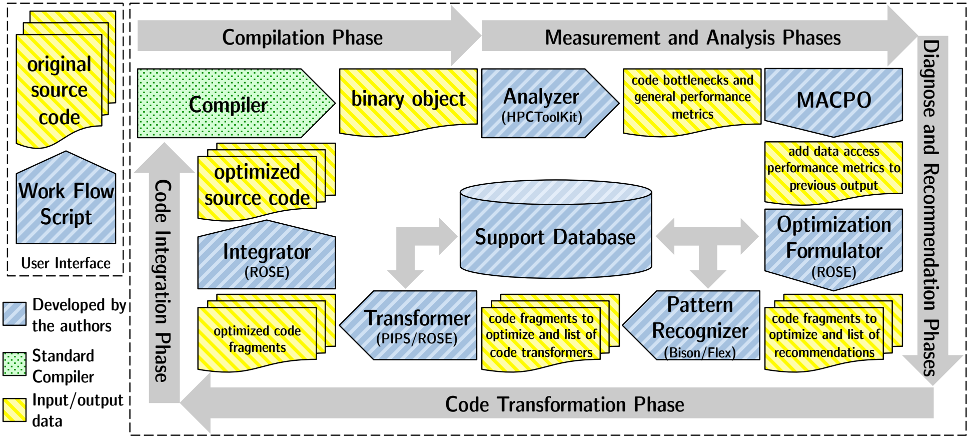
- Based on ROSE
- **Extendable:** accepts user-defined performance metrics
- **Extendable:** it is possible to write new *"recommendation selection functions"* (SQL query)

How PerfExpert does that: Support Database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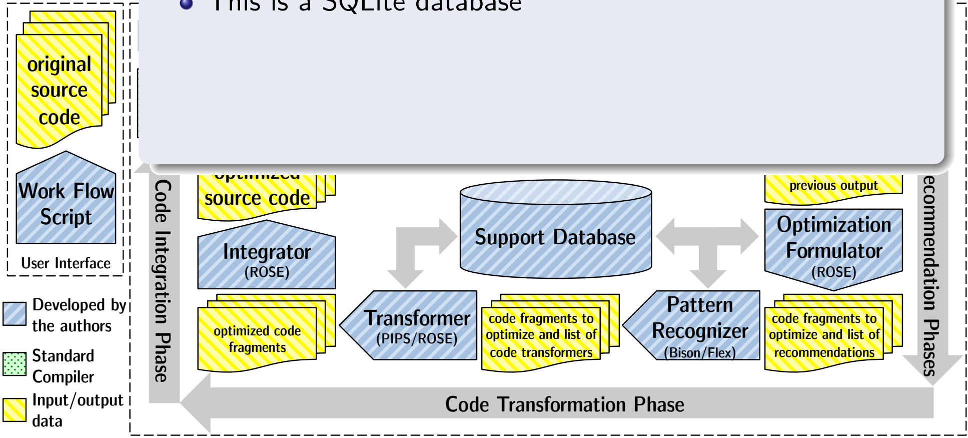
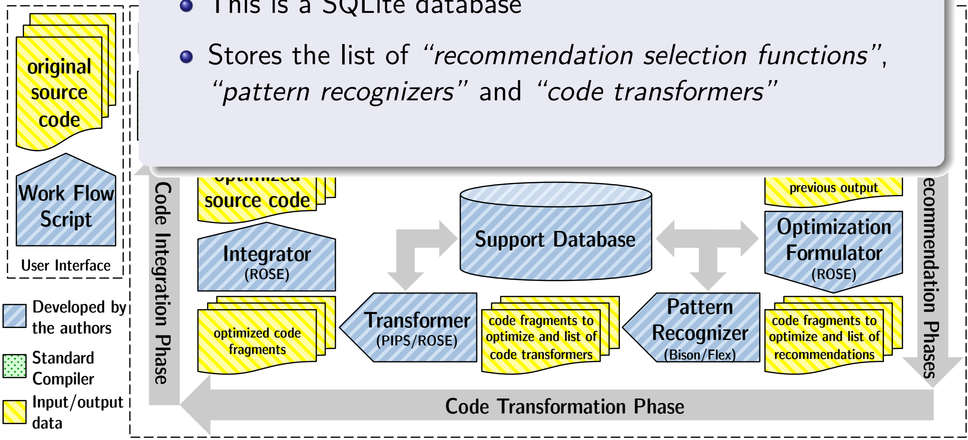
How PerfExpert does that: Support Database

- This is a SQLite database



How PerfExpert does that: Support Database

- This is a SQLite database
- Stores the list of *“recommendation selection functions”*, *“pattern recognizers”* and *“code transformers”*



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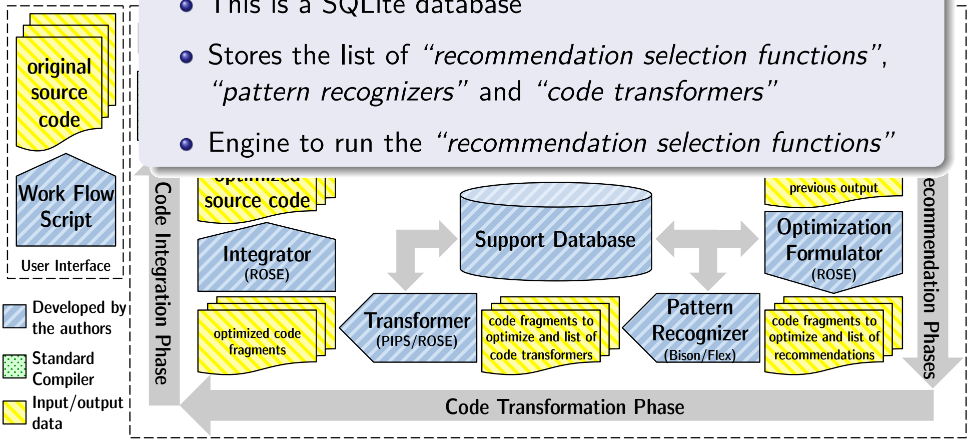
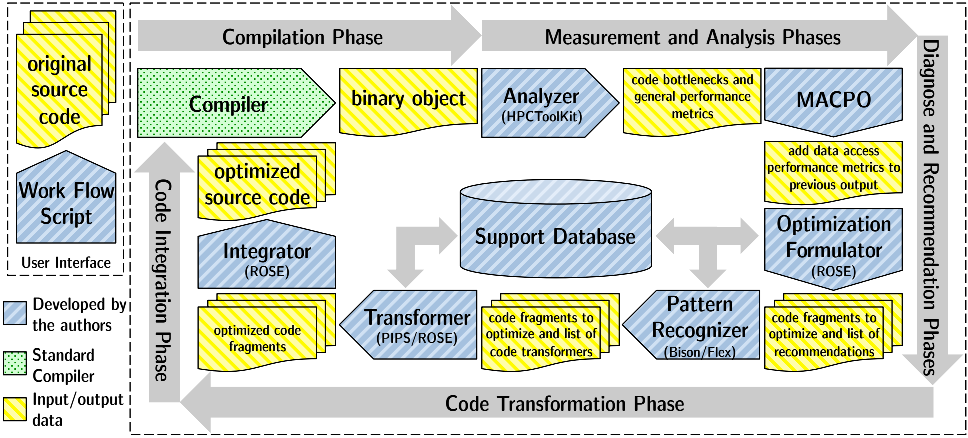


- This is a SQLite database
- Stores the list of *"recommendation selection functions"*, *"pattern recognizers"* and *"code transformers"*
- Engine to run the *"recommendation selection functions"*

How PerfExpert does that: Pattern Recognizer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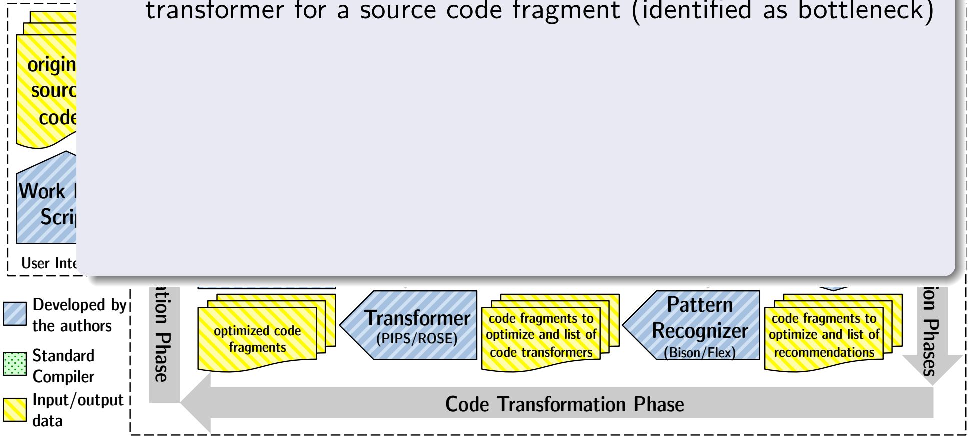
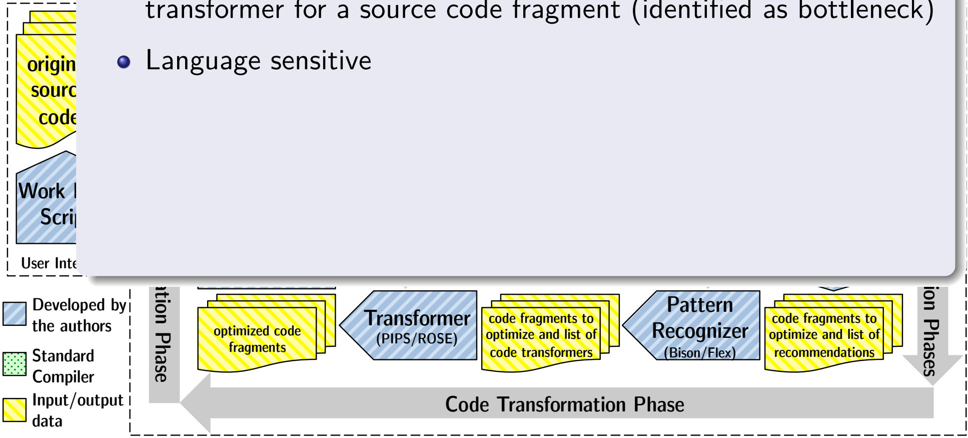
How PerfExpert does that: Pattern Recognizer

- Acts as a "filter" trying to find (match) the right code transformer for a source code fragment (identified as bottleneck)



How PerfExpert does that: Pattern Recognizer

- Acts as a “filter” trying to find (match) the right code transformer for a source code fragment (identified as bottleneck)
- Language sensitive



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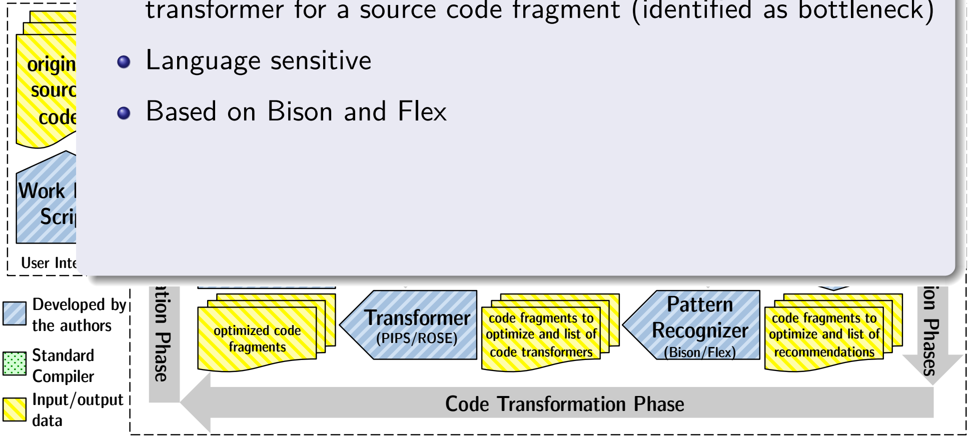

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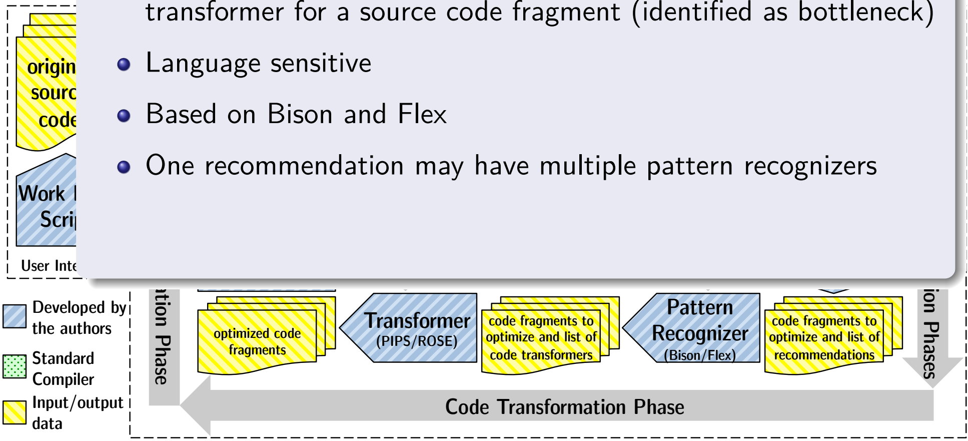

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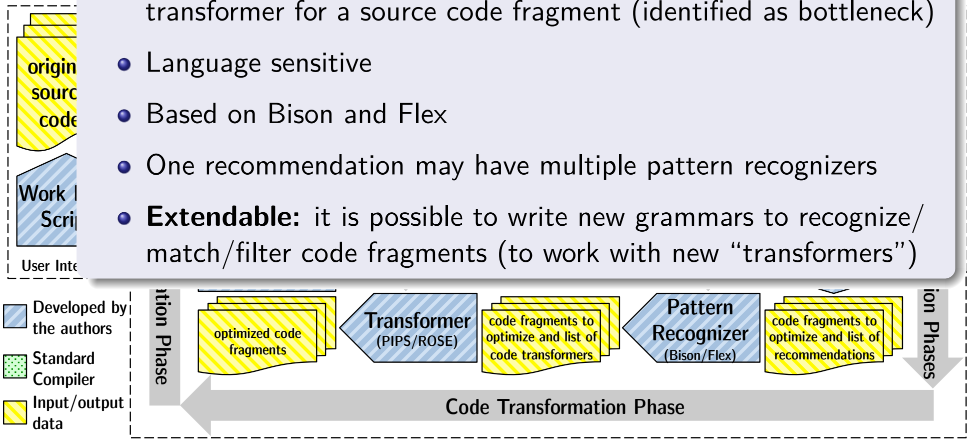
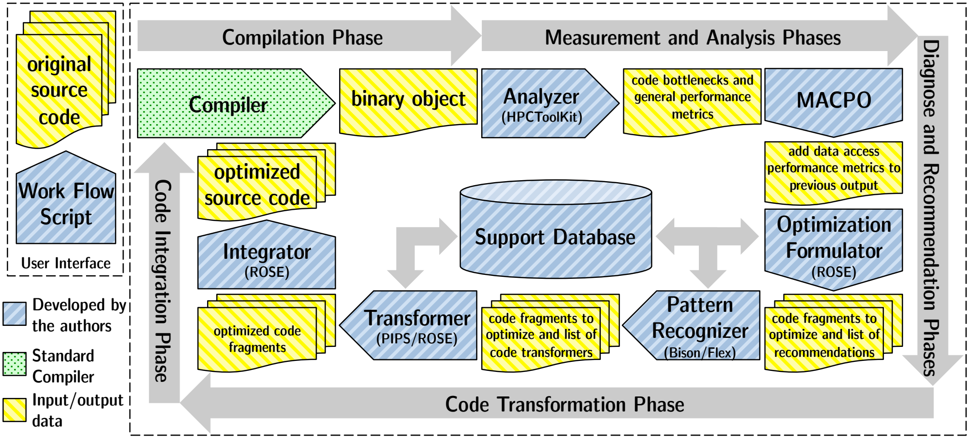
- Acts as a “filter” trying to find (match) the right code transformer for a source code fragment (identified as bottleneck)
- Language sensitive
- Based on Bison and Flex
- One recommendation may have multiple pattern recognizers
- **Extendable:** it is possible to write new grammars to recognize/match/filter code fragments (to work with new “transformers”)



How PerfExpert does that: Transformer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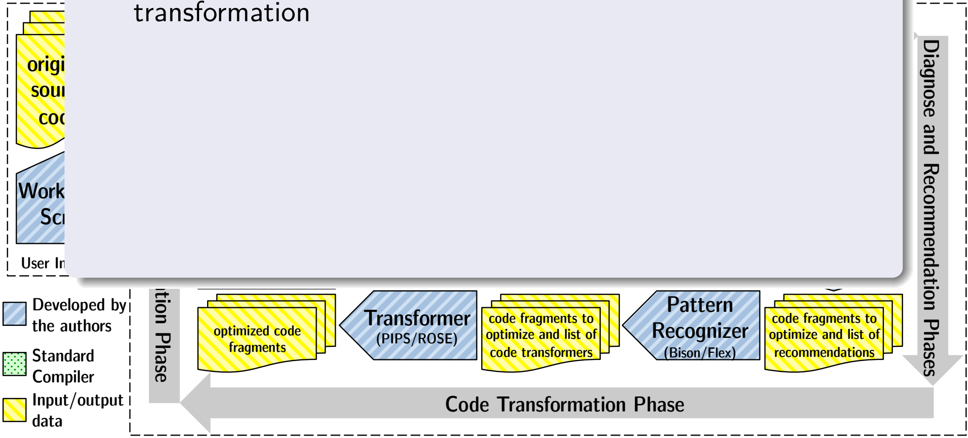
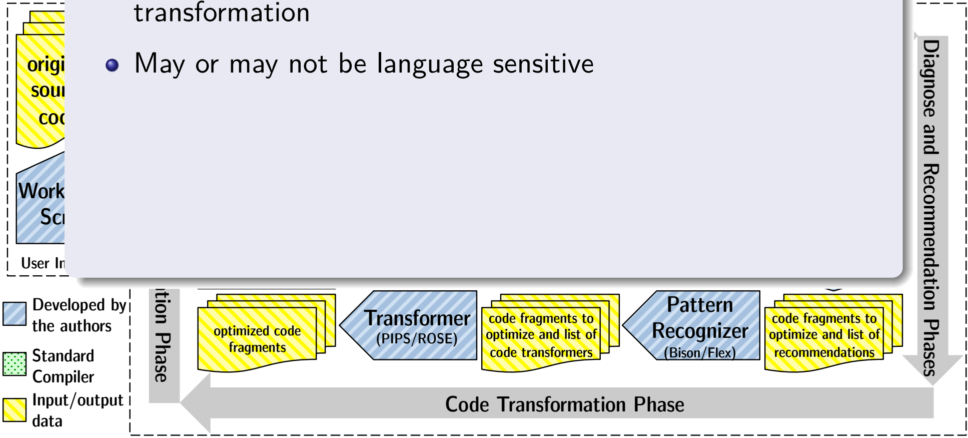
How PerfExpert does that: Transformer

- Implements the recommendation by applying source code transformation



How PerfExpert does that: Transformer

- Implements the recommendation by applying source code transformation
- May or may not be language sensitive



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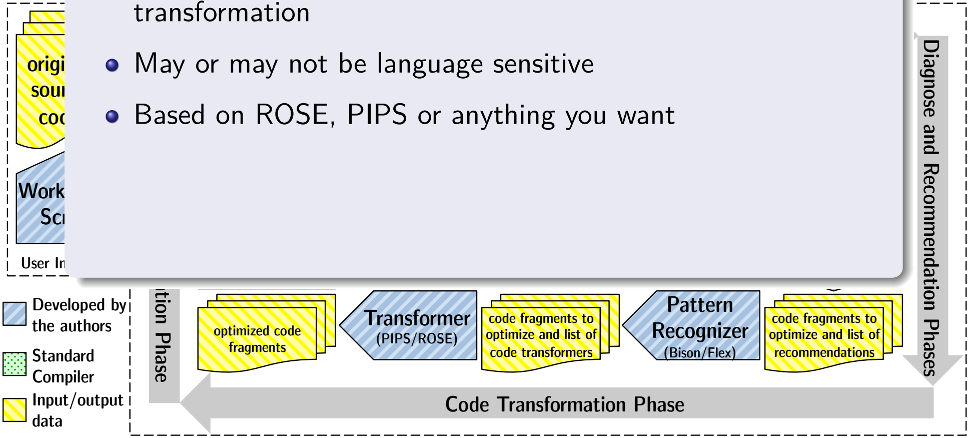
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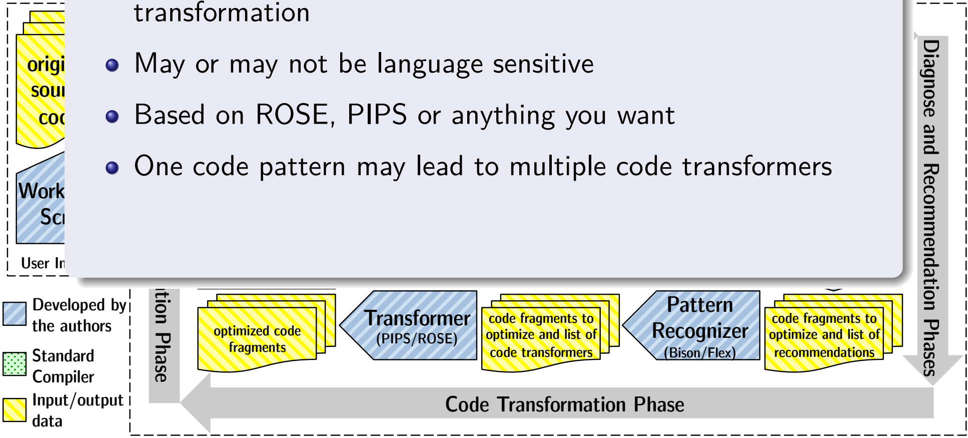

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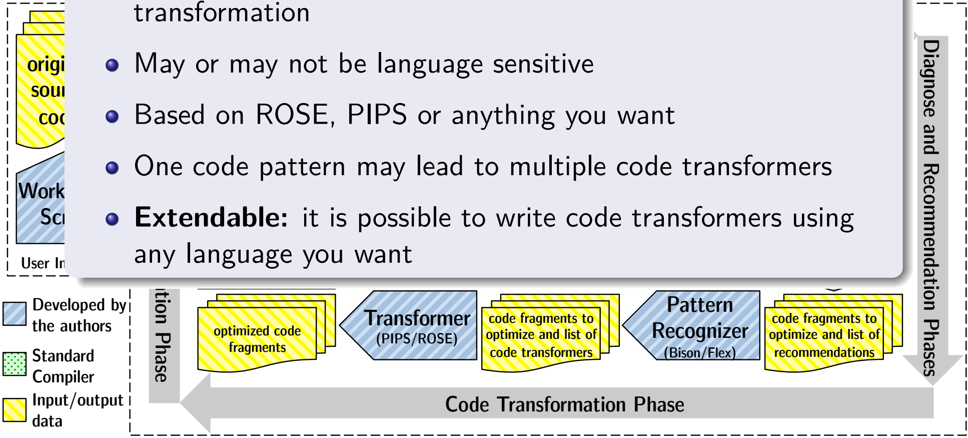
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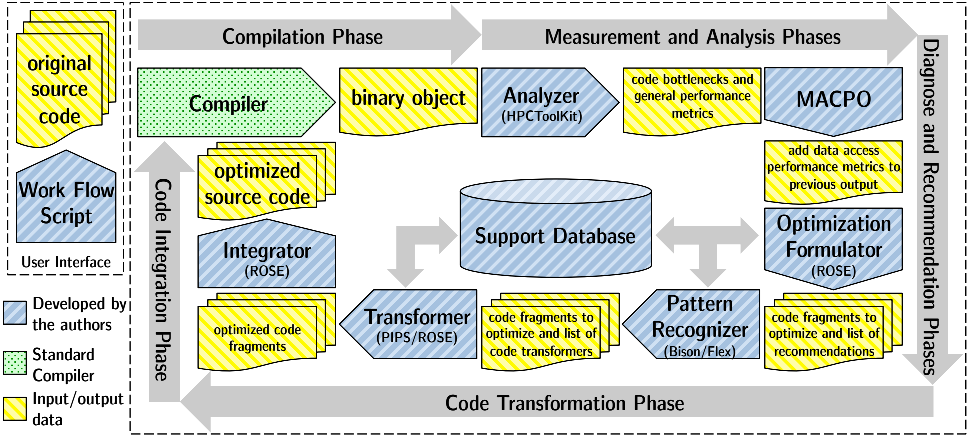
How PerfExpert does that: Integrator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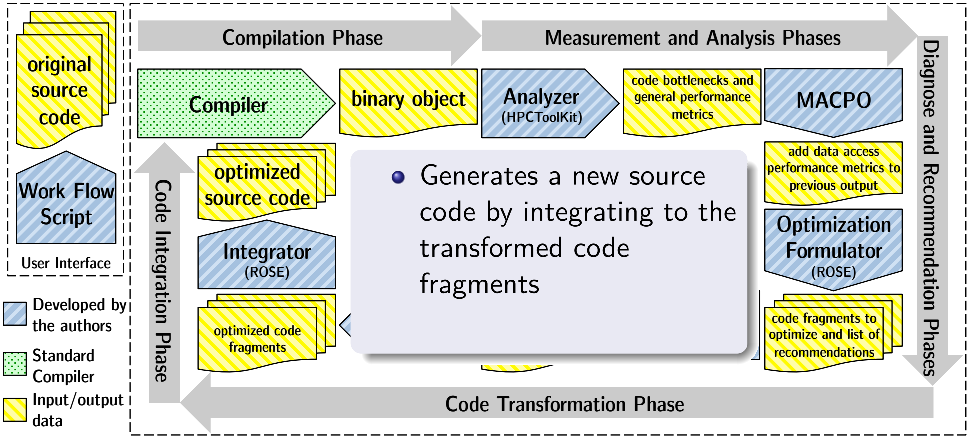
How PerfExpert does that: Integrator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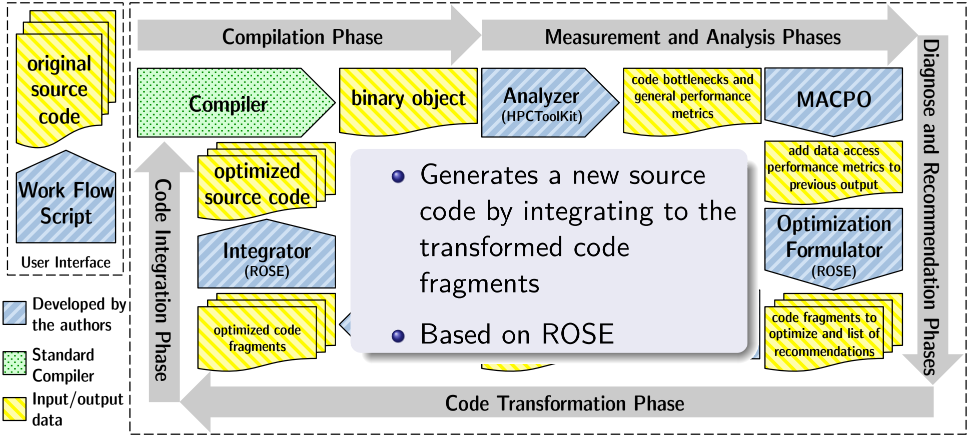
How PerfExpert does that: Integrator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- Generates a new source code by integrating to the transformed code fragments
- Based on ROSE

How PerfExpert does that: Key Points

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Why is this performance optimization “architecture” strong?

How PerfExpert does that: Key Points

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- Multi-language, **multi-architecture**, open-source and built on top of well-established tools (HPCToolKit, ROSE, PIPS, etc.)
- Easy to use and lightweight!

Extending PerfExpert

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- Adding performance metrics

Extending PerfExpert

- Adding performance metrics
- Optimization recommendations [entries on the SQL database]

Extending PerfExpert

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Extending PerfExpert

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Adding Performance Metrics

Extending PerfExpert

Adding Performance Metrics

```
code.section_info=Loop in function compute() at mm.c:8
code.filename=mm.c
code.line_number=8
code.type=loop
code.function_name=compute
code.extra_info=3
code.representativeness=99.8
perfexpert.ratio.data_accesses=0.25
perfexpert.instruction_accesses.L2i_hits=0.002
perfexpert.branch_instructions.mispredicted=0.0
perfexpert.floating-point_instr.fast_FP_instr=5.073
perfexpert.data_accesses.L2d_hits=1.846
...
```

Extending PerfExpert

Extending PerfExpert

Recommendation Selection Functions

Extending PerfExpert

Recommendation Selection Functions

```
SELECT r.id AS recommendation_id, SUM(
  (CASE c.short WHEN 'd-l1' THEN
    (m.data_accesses_L1d_hits - (max * 0.1))
    ELSE 0 END) +
    ...  )  AS score FROM recommendation AS r
JOIN metric AS m JOIN (SELECT MAX(
  m.data_accesses_L1d_hits, m.data_accesses_L2d_hits,
  ...  )  AS max
  FROM metric AS m WHERE m.overall * 100 /
    (0.5 * (100 - m.ratio_floating_point) +
    m.ratio_floating_point) > 1
  AND m.id = @RID)
WHERE (r.loop <= @LPD AND m.code_type = 'loop') OR
  (r.loop IS NULL AND m.code_type = 'function')
  AND m.id = @RID
GROUP BY r.id ORDER BY score DESC;
```

Extending PerfExpert

Extending PerfExpert

Pattern Recognizers

Extending PerfExpert

Pattern Recognizers

```
nested_iteration_statement
:  WHILE '(' exp ')' WHILE '(' exp ')' stmnt
| WHILE '(' exp ')' '' WHILE '(' exp ')' stmnt ''
| DO DO stmnt WHILE '(' exp ')' ';' stmnt WHILE '(' exp ')' ';'
| DO '' DO stmnt WHILE '(' exp ')' ';' '' WHILE '(' exp ')' ';'
| FOR '(' exp_stmnt exp_stmnt ')' FOR '(' exp_stmnt exp_stmnt ')' stmnt
| FOR '(' exp_stmnt exp_stmnt ')' '' FOR '(' exp_stmnt exp_stmnt ')' stmnt ''
| FOR '(' exp_stmnt exp_stmnt exp ')' FOR '(' exp_stmnt exp_stmnt exp ')' stmnt
| FOR '(' exp_stmnt exp_stmnt exp ')' '' FOR '(' exp_stmnt exp_stmnt exp ')' stmnt '' ;
```

Extending PerfExpert

Extending PerfExpert

Code Transformers

Extending PerfExpert

Code Transformers

```
create c_loop2 ../source/mm.c
activate INTERPROCEDURAL_SUMMARY_PRECONDITION
activate TRANSFORMERS_INTER_FULL
activate PRECONDITIONS_INTER_FULL
setproperty SEMANTICS_FIX_POINT_OPERATOR ‘‘derivative’’
module compute
apply LOOP_INTERCHANGE
loop_8
apply UNSPLIT[%PROGRAM]
close
quit
```

Hands on Tutorial

Accessing Stampede:

- `ssh login@stampede.tacc.utexas.edu`
- use the password that has been provided to you

Request a Compute Node:

- `./reserve`
- now we are ready to go...

Hands on Tutorial

Accessing Stampede:

- `cd 1`
- `perfexpert`
- `perfexpert -s mm.c mm`
- `grep -R "running time" *`
- `more mm.c`
- `more perfexpert-temp-zUKfkx7/1/fragments/new/mm.c`
- `perfexpert mm`
- `perfexpert -r 5 mm`
- `cd ../2`
- `perfexpert -m -s backprop.c backprop`

Agenda

Agenda

What we saw in the morning:

- Introduction and motivation
- What PerfExpert can provide to you?
- Demo
- How PerfExpert does that? (opening Pandora's box)
- Extending PerfExpert
- Hands on tutorial
- Morning closure

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What we will see in the afternoon:

How to enhance the application performance using memory access metrics (MAPCO)

Agenda

Short Demo

Short demo

Agenda

Performance Optimization by Mapping to Accelerators

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Mapping of code segments to accelerators is becoming one of the most methods for optimizing the performance of an application

Performance Optimization by Mapping to Accelerators

Mapping of code segments to accelerators is becoming one of the most methods for optimizing the performance of an application

Problem: how to select those parts of an application which will benefit from execution on an accelerator?

Code Segments for SIMT/SIMD Execution

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- Optimize for multicore chip execution — **PerfExpert, why?**

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Code Segments for SIMT/SIMD Execution

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- Eliminate kernels not easily mappable for SIMT/SIMD execution — **How?**

Code Segments for SIMT/SIMD Execution

- Optimize for multicore chip execution — **PerfExpert, why?**
- Identify time consuming kernels in code — **PerfExpert**
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- Characterize the kernels suitable for SIMT/SIMD execution — **What properties?**

Code Segments for SIMT/SIMD Execution

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- Identify time consuming kernels in code — **PerfExpert**
- Eliminate kernels not easily mappable for SIMT/SIMD execution — **How?**
- Characterize the kernels suitable for SIMT/SIMD execution — **What properties?**
- Rank appropriate kernels using the characteristics identified in the last step

Code Segments for SIMT/SIMD Execution

- Optimize for multicore chip execution — **PerfExpert, why?**
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- Eliminate kernels not easily mappable for SIMT/SIMD execution — **How?**
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- Rank appropriate kernels using the characteristics identified in the last step
- Estimate cost of data movement

Code Segments for SIMT/SIMD Execution

- Optimize for multicore chip execution — **PerfExpert, why?**
- Identify time consuming kernels in code — **PerfExpert**
- Eliminate kernels not easily mappable for SIMT/SIMD execution — **How?**
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- Look for refactorings that will enable leaving data on accelerator

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- Generate compiler annotations for translation of C/C++/Fortran to CUDA/OpenCL

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- Optimize for multicore chip execution — **PerfExpert, why?**
- Identify time consuming kernels in code — **PerfExpert**
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- Characterize the kernels suitable for SIMT/SIMD execution — **What properties?**
- Rank appropriate kernels using the characteristics identified in the last step
- Estimate cost of data movement
- Look for refactorings that will enable leaving data on accelerator
- Generate compiler annotations for translation of C/C++/Fortran to CUDA/OpenCL
- Suggest kernels needing new algorithms

Code Segments for SIMT/SIMD Execution

Code Segments for SIMT/SIMD Execution

Unsuitable Kernels

Code Segments for SIMT/SIMD Execution

Unsuitable Kernels

- Frequent TLB misses

Code Segments for SIMT/SIMD Execution

Unsuitable Kernels

- Frequent TLB misses
- High fraction of branches

Code Segments for SIMT/SIMD Execution

Unsuitable Kernels

- Frequent TLB misses
- High fraction of branches
- Cache conflicts across cores

Code Segments for SIMT/SIMD Execution

Unsuitable Kernels

- Frequent TLB misses
- High fraction of branches
- Cache conflicts across cores
- Irregular access strides for kernel data structures

Characterizing “Good” Kernels

Code Segments for SIMT/SIMD Execution

Unsuitable Kernels

- Frequent TLB misses
- High fraction of branches
- Cache conflicts across cores
- Irregular access strides for kernel data structures

Characterizing "Good" Kernels

- Computational intensity

Code Segments for SIMT/SIMD Execution

Unsuitable Kernels

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- High fraction of branches
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- Irregular access strides for kernel data structures

Characterizing "Good" Kernels

- Computational intensity
- Pure "local" SPMD parallelism

Code Segments for SIMT/SIMD Execution

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- High fraction of branches
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- Computational intensity
- Pure “local” SPMD parallelism
- Streaming parallelism or vectorization

Code Segments for SIMT/SIMD Execution

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Characterizing "Good" Kernels

- Computational intensity
- Pure "local" SPMD parallelism
- Streaming parallelism or vectorization
- Regular access strides for data structures
- Data reuse factor and data transfer volume

Code Segments for SIMT/SIMD Execution

Unsuitable Kernels

- Frequent TLB misses
- High fraction of branches
- Cache conflicts across cores
- Irregular access strides for kernel data structures

Characterizing "Good" Kernels

- Computational intensity
- Pure "local" SPMD parallelism
- Streaming parallelism or vectorization
- Regular access strides for data structures
- Data reuse factor and data transfer volume
- "Limited" recursion

Code Segments for SIMT/SIMD Execution

Code Segments for SIMT/SIMD Execution

Ranking “Good” Kernels

Code Segments for SIMT/SIMD Execution

Ranking "Good" Kernels

- Curve fit characteristics to speed-up measurements of kernels that have already been mapped

Code Segments for SIMT/SIMD Execution

Ranking “Good” Kernels

- Curve fit characteristics to speed-up measurements of kernels that have already been mapped
- Sort by values of characteristics in some chosen order

Code Segments for SIMT/SIMD Execution

Ranking “Good” Kernels

- Curve fit characteristics to speed-up measurements of kernels that have already been mapped
- Sort by values of characteristics in some chosen order
- Hold up your thumb?

Example

Example

Agenda

Thank You