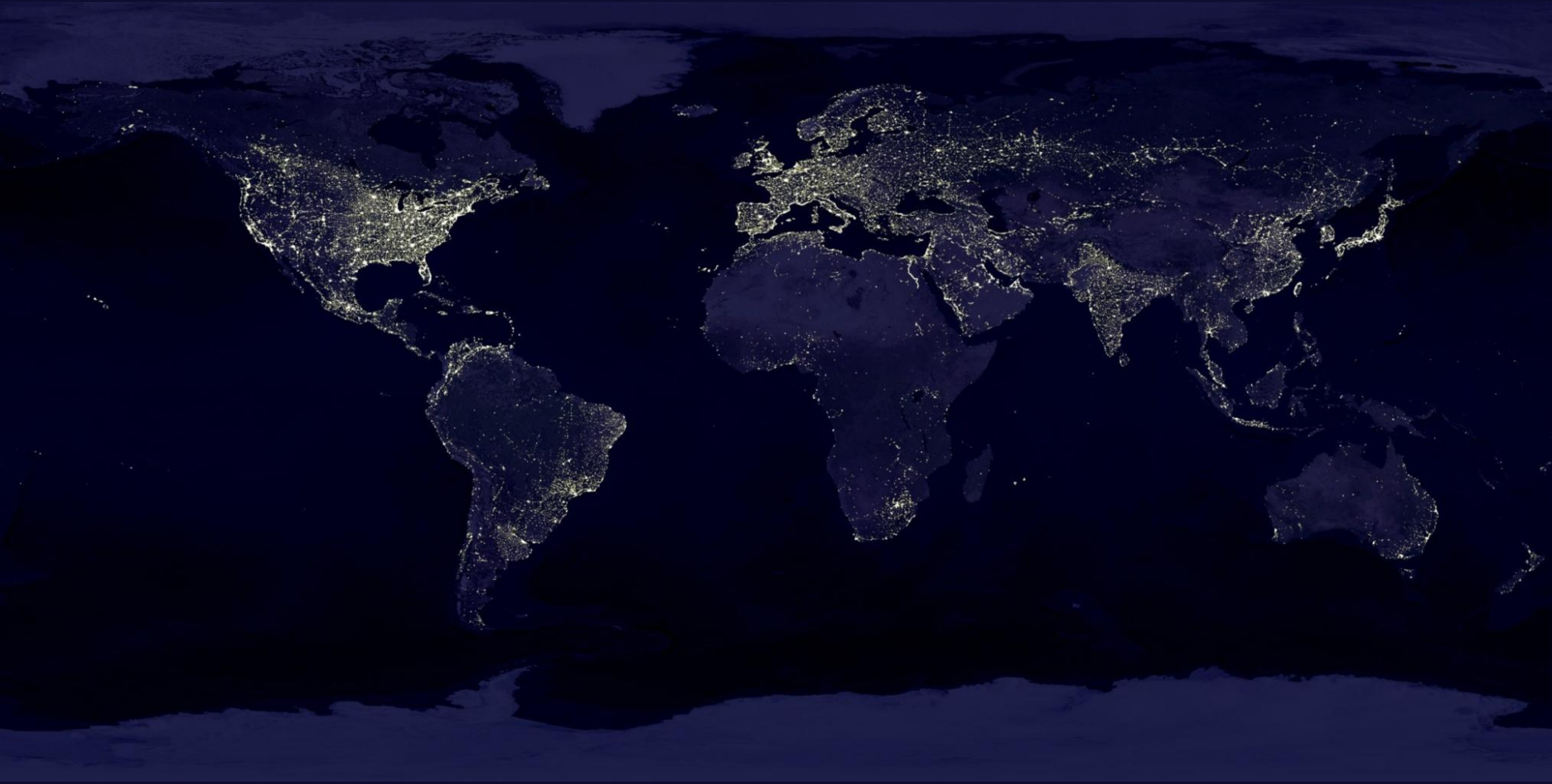
# Collective Mind infrastructure and repository to crowdsource auto-tuning



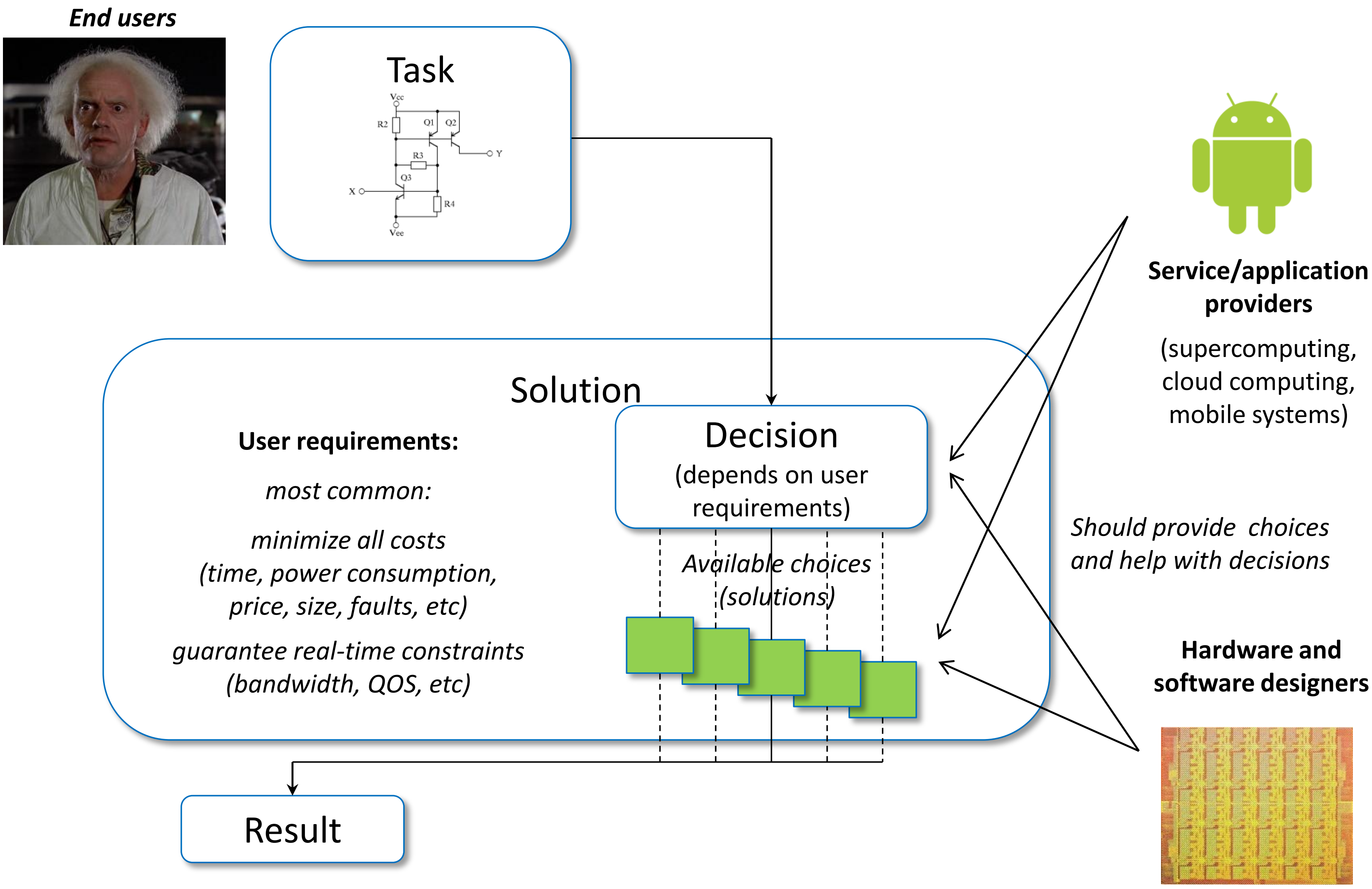
Grigori Fursin INRIA, France

April 2013

# Background

- Collective Mind approach combined with expert knowledge and predictive modeling
- Collective Mind framework basics
  - Plugin-based type-free and schema-free infrastructure
  - Portable file (json) based repository
  - Auto-tuning and predictive modeling scenarios
- Demo
- Conclusions and future works

# Motivation: back to basics



***End users***

Task

Solution

**User requirements:**

*most common:*

*minimize all costs (time, power consumption, price, size, faults, etc)*

*guarantee real-time constraints (bandwidth, QOS, etc)*

Decision (depends on user requirements)

*Available choices (solutions)*

Result

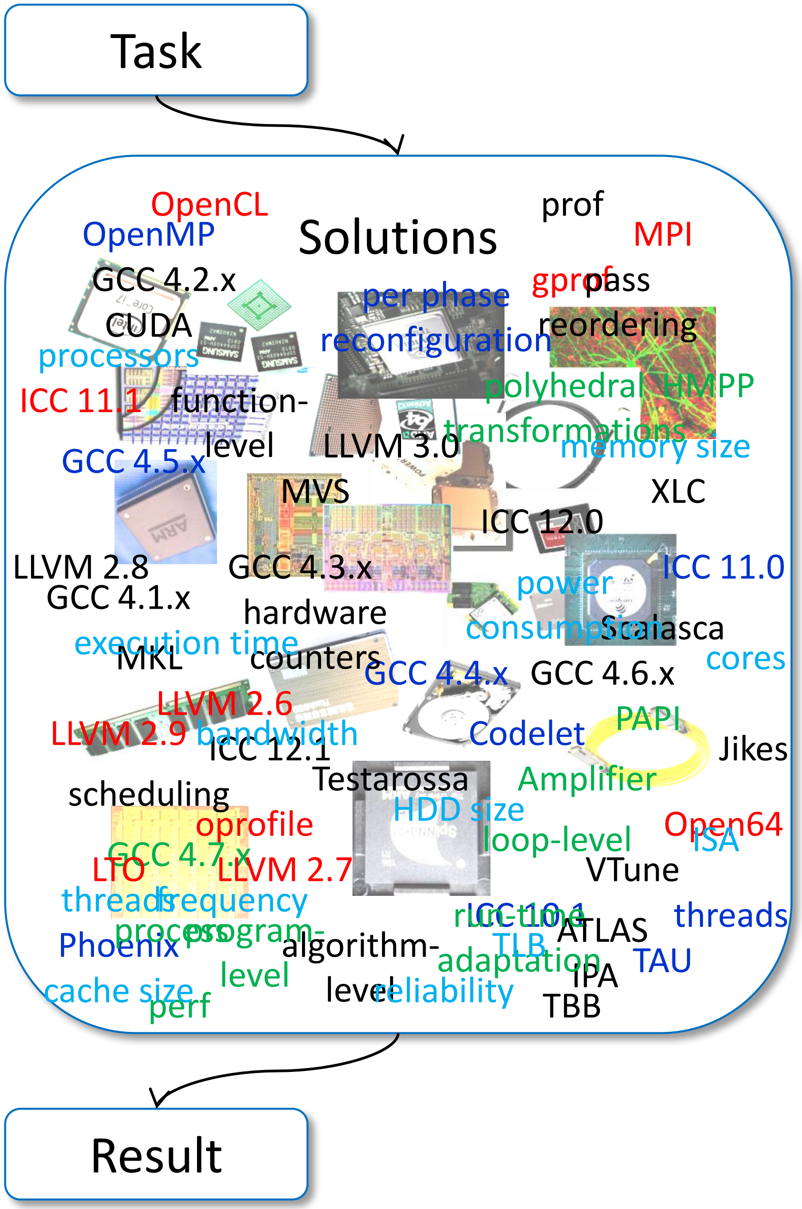
**Service/application providers**

(supercomputing, cloud computing, mobile systems)

*Should provide choices and help with decisions*

**Hardware and software designers**

# Challenges



Task

OpenCL
OpenMP
Solutions
prof
MPI
GCC 4.2.x
per phase
gprof
pass
CUDA
reconfiguration
reordering
processors
polyhedral
HMPP
ICC 11.1
function-level
transformations
memory size
GCC 4.5.x
LLVM 3.0
MVS
XLC
ICC 12.0
LLVM 2.8
GCC 4.3.x
ICC 11.0
power consumption
GCC 4.1.x
hardware counters
Scalasca
execution time
MKL
GCC 4.4.x
GCC 4.6.x
cores
LLVM 2.6
PAPI
LLVM 2.9
bandwidth
ICC 12.1
Codelet
Jikes
scheduling
Testarossa
Amplifier
HDD size
oprofile
loop-level
Open64
ISA
GCC 4.7.x
LTO
LLVM 2.7
VTune
threads
frequency
ICC 10.1
run-time adaptation
threads
Phoenix
processor
program-level
algorithm-level
TLB
ATLAS
TAU
IPA
cache size
perf
reliability
TBB

Result

## Clean up this mess!

**Simplify analysis, tuning and modelling of computer systems for non-computer engineers**

**Bring together researchers from interdisciplinary communities**

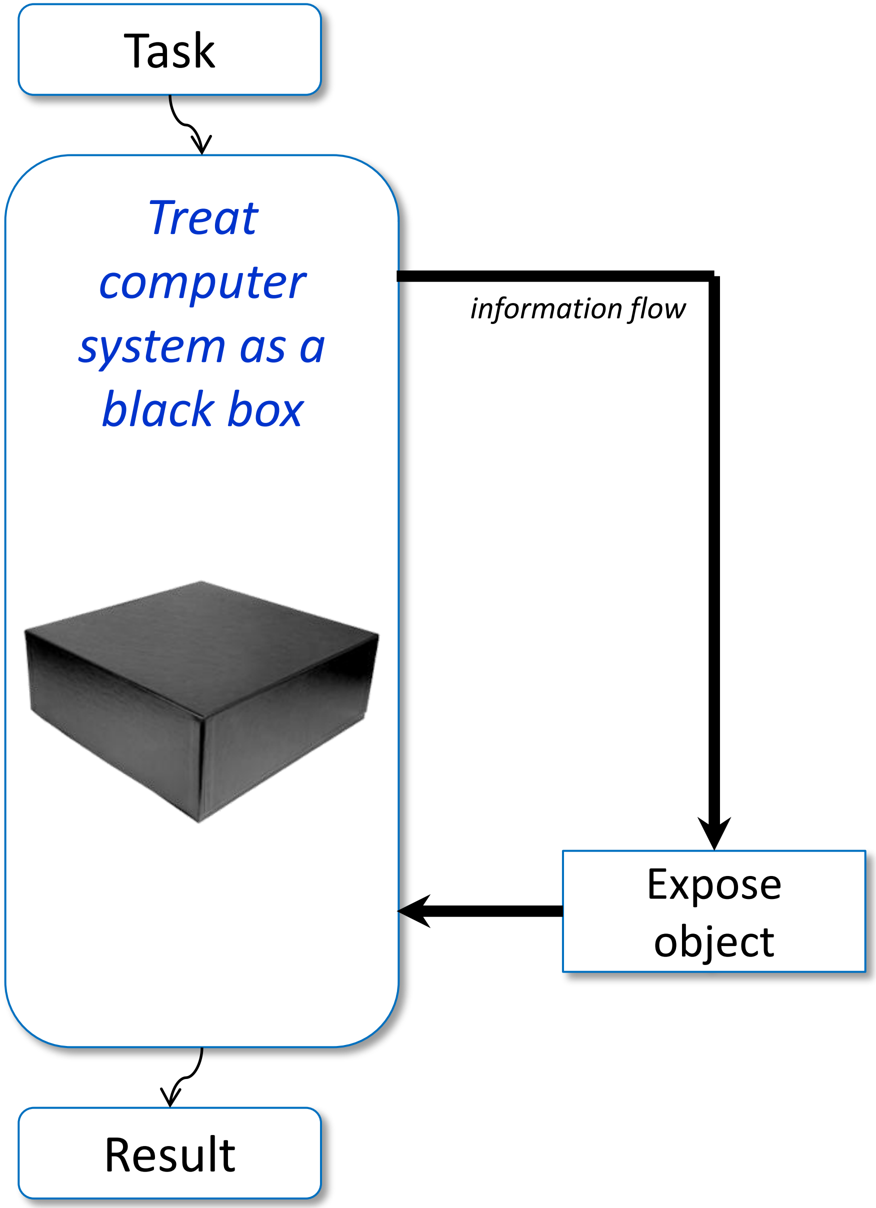
# Understanding computer systems' behavior: a physicist's approach

Task

*Treat computer system as a black box*

Result

# Understanding computer systems' behavior: a physicist's approach



Task

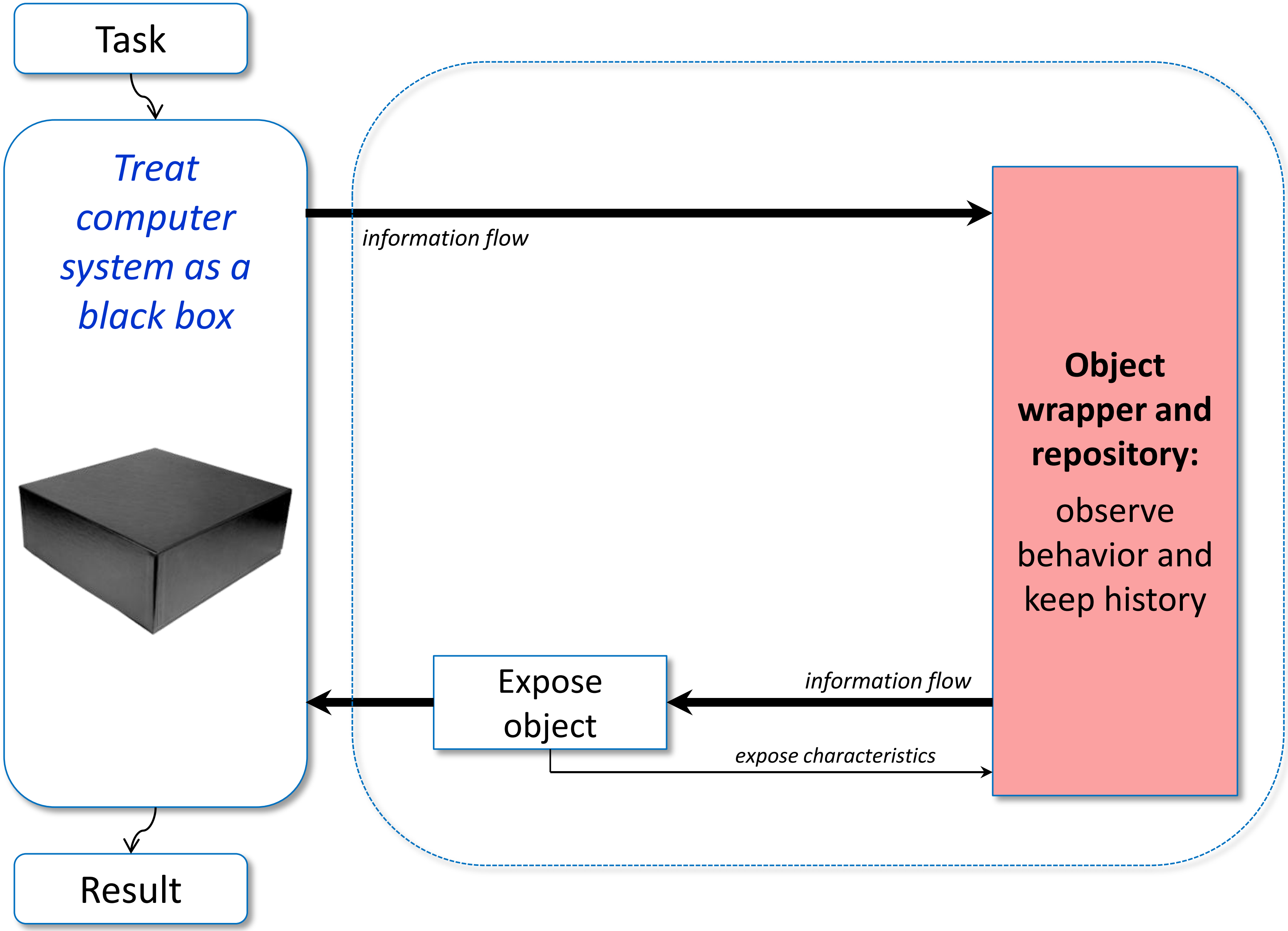
*Treat computer system as a black box*

*information flow*

Expose object

Result

# Observe system



Task

*Treat computer system as a black box*

*information flow*

**Object wrapper and repository:**

observe behavior and keep history

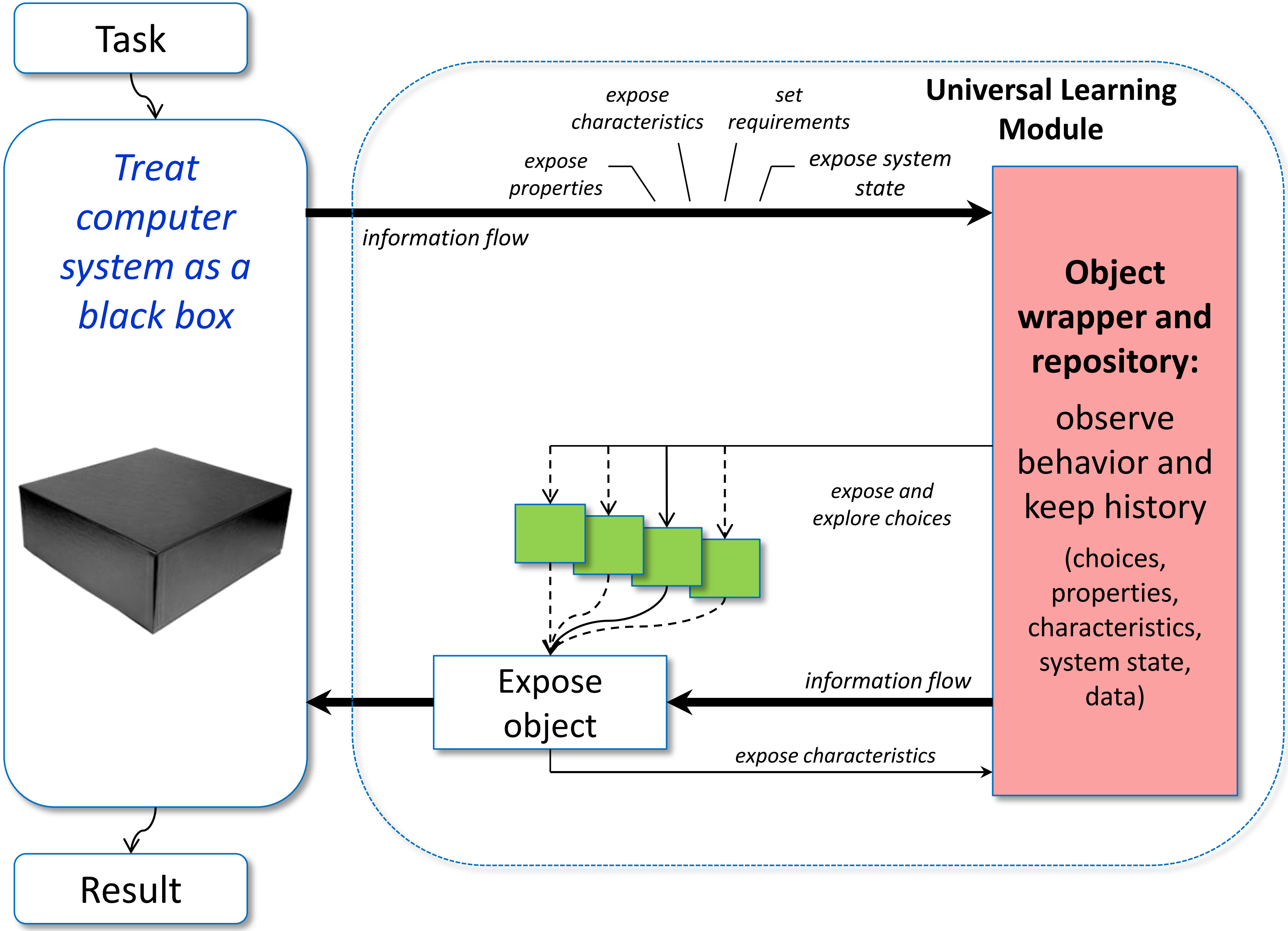
Expose object

*information flow*

*expose characteristics*

Result

# Gradually expose properties, characteristics, choices



Task

*Treat computer system as a black box*

Result

**Universal Learning Module**

*expose characteristics*

*set requirements*

*expose properties*

*expose system state*

*information flow*

**Object wrapper and repository:**

observe behavior and keep history

(choices, properties, characteristics, system state, data)

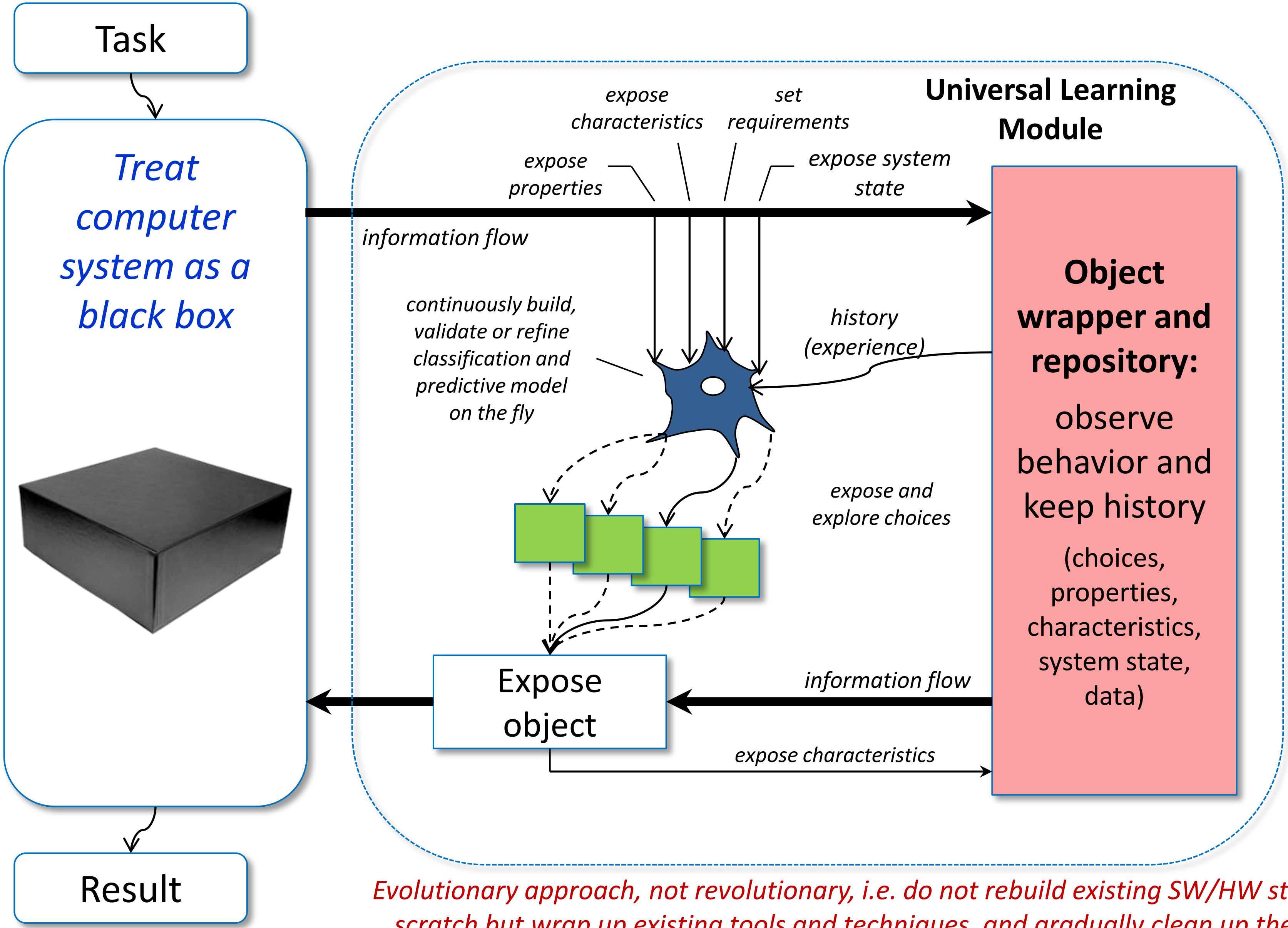
*expose and explore choices*

Expose object

*information flow*

*expose characteristics*

# Classify, build models, predict behavior



Task

*Treat computer system as a black box*

Result

**Universal Learning Module**

*expose characteristics*

*set requirements*

*expose properties*

*expose system state*

*information flow*

*continuously build, validate or refine classification and predictive model on the fly*

*history (experience)*

*expose and explore choices*

Expose object

*information flow*

*expose characteristics*

**Object wrapper and repository:**

observe behavior and keep history

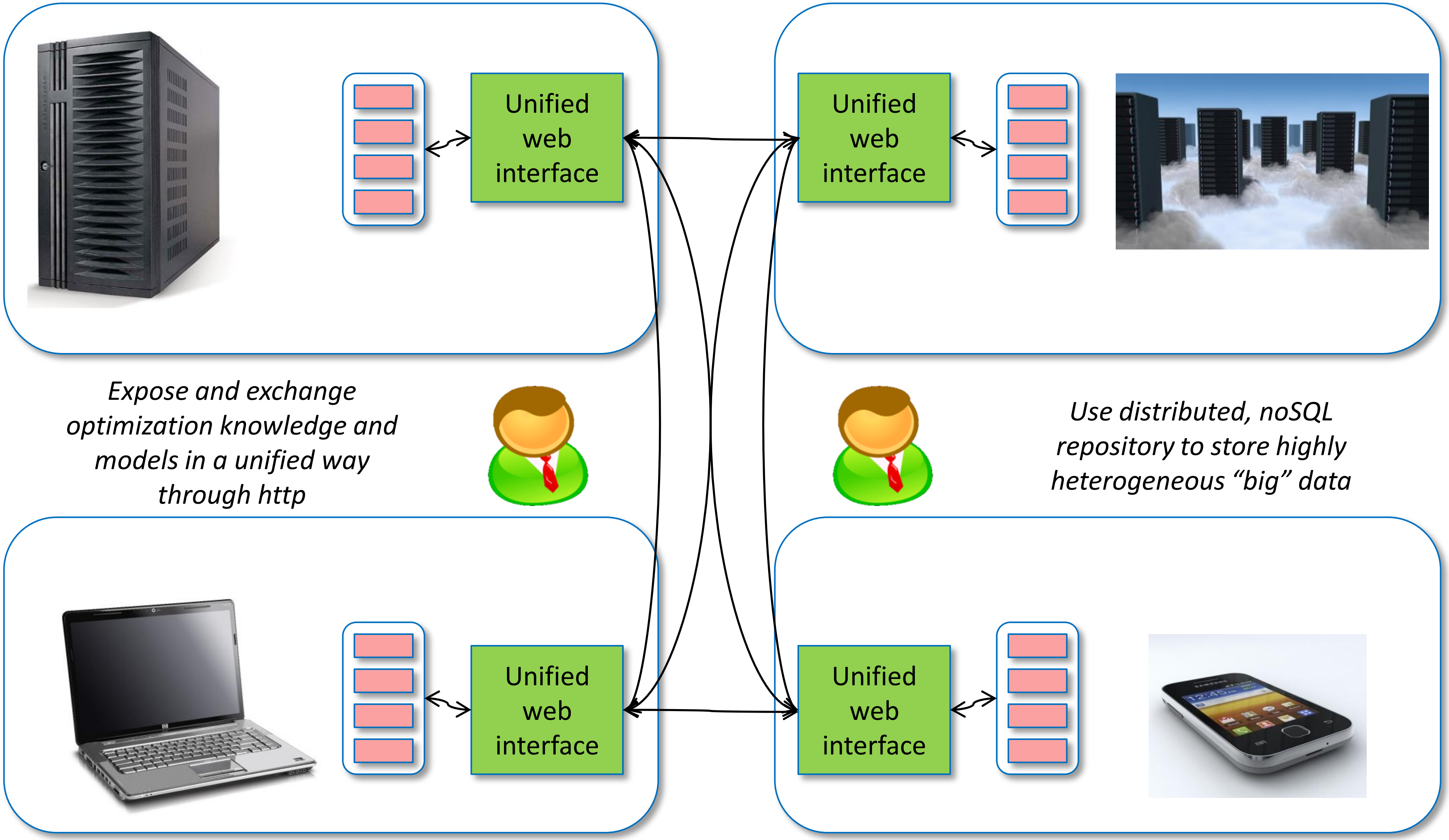
(choices, properties, characteristics, system state, data)

*Evolutionary approach, not revolutionary, i.e. do not rebuild existing SW/HW stack from scratch but wrap up existing tools and techniques, and gradually clean up the mess!*

# Transparently crowdsource learning of a behavior of any existing mobile, cluster, cloud computer system

***Extrapolate collective knowledge to build faster and more power efficient computer systems***

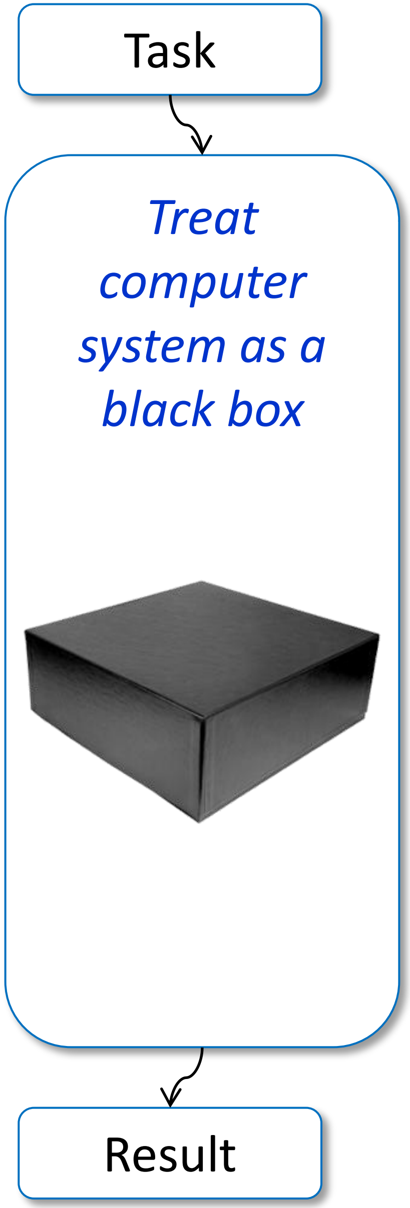
***Build self-tuning machines using agent-based models***

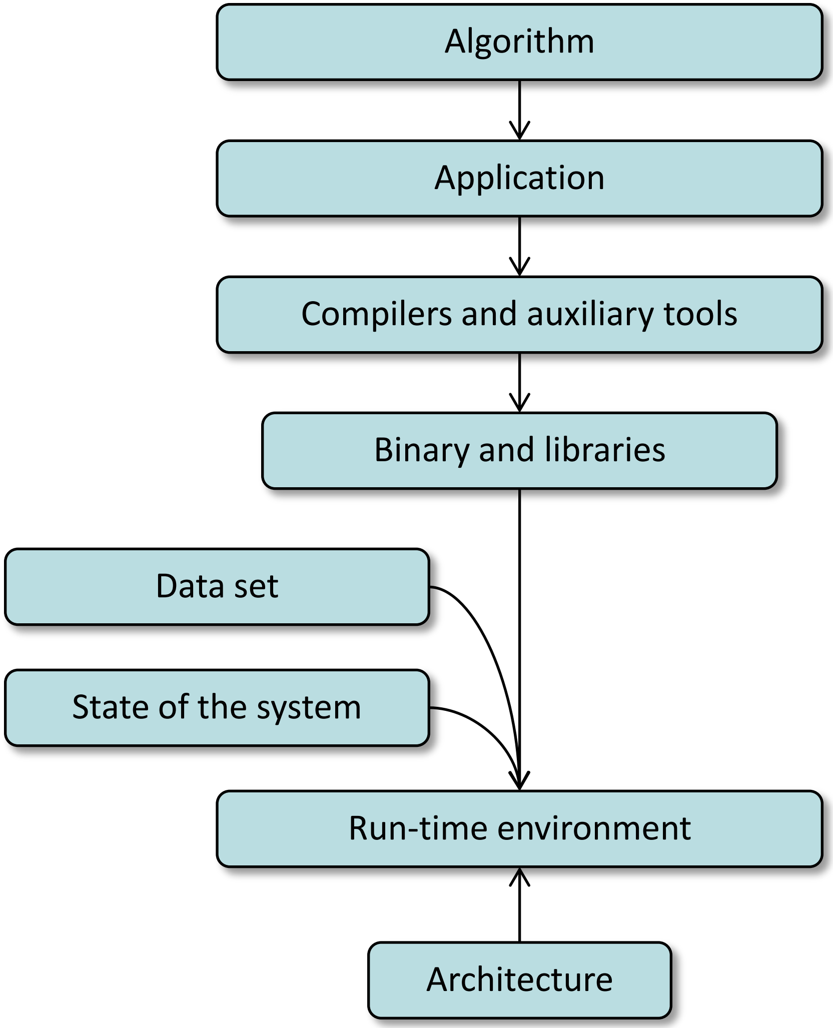


*Expose and exchange optimization knowledge and models in a unified way through http*

*Use distributed, noSQL repository to store highly heterogeneous "big" data*

# Gradual decomposition, parameterization, observation and exploration of a system





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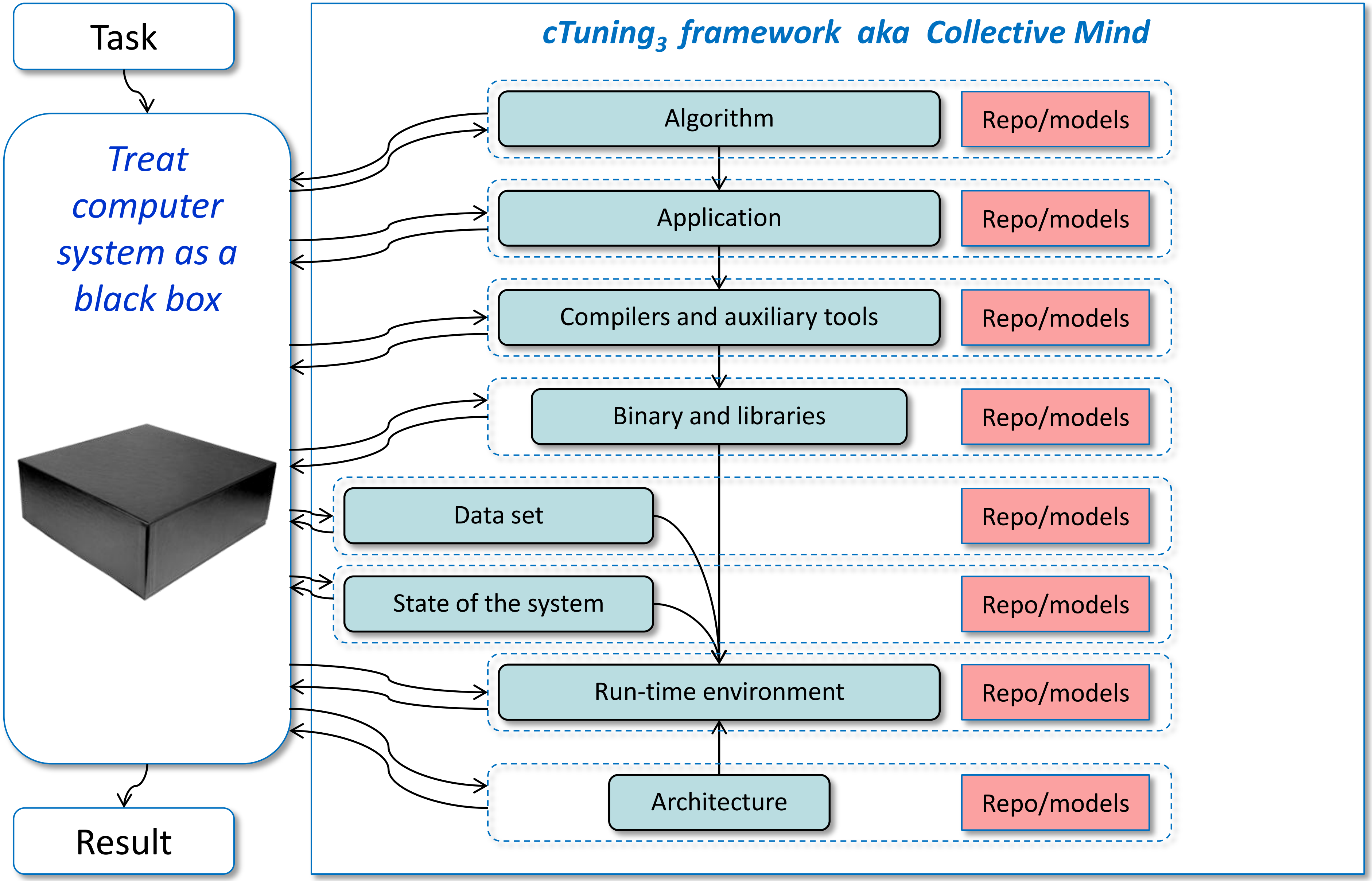
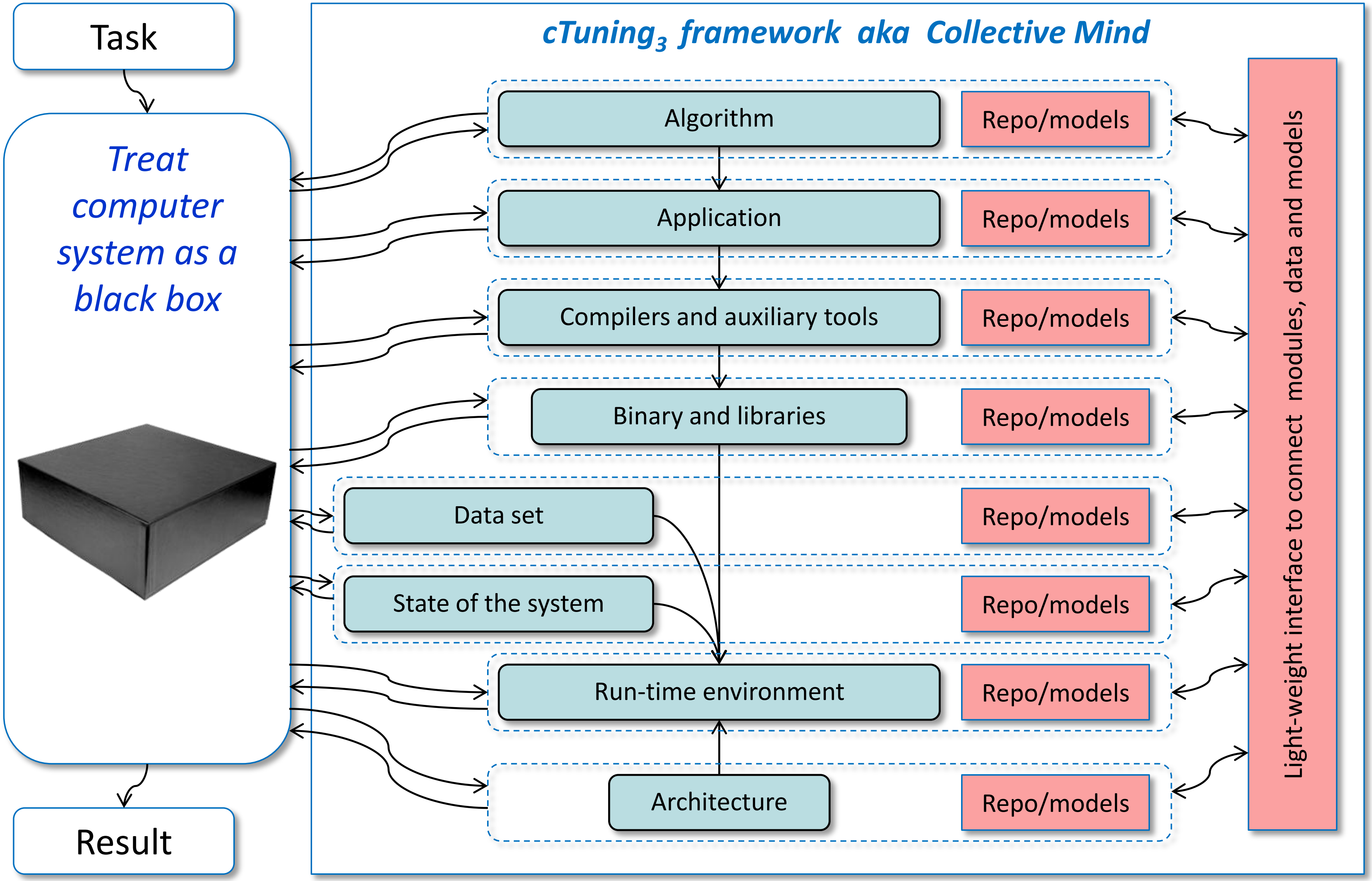
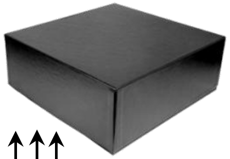


# Gradual top-down decomposition, parameterization, observation and exploration of a system



# Example of characterizing/explaining behavior of computer systems



| | | Gradually expose some characteristics | Gradually expose some properties/choices |
|---|---|---|---|
| Compile Program | | time … | compiler flags; pragmas … |
| Run code | Run-time environment | time; CPI, power consumption … | pinning/scheduling … |
| | System | cost; | architecture; frequency; cache size… |
| | Data set | size; values; description … | precision … |
| Analyze profile | | time; size … | instrumentation; profiling … |

***Combine expert knowledge with automatic detection!***

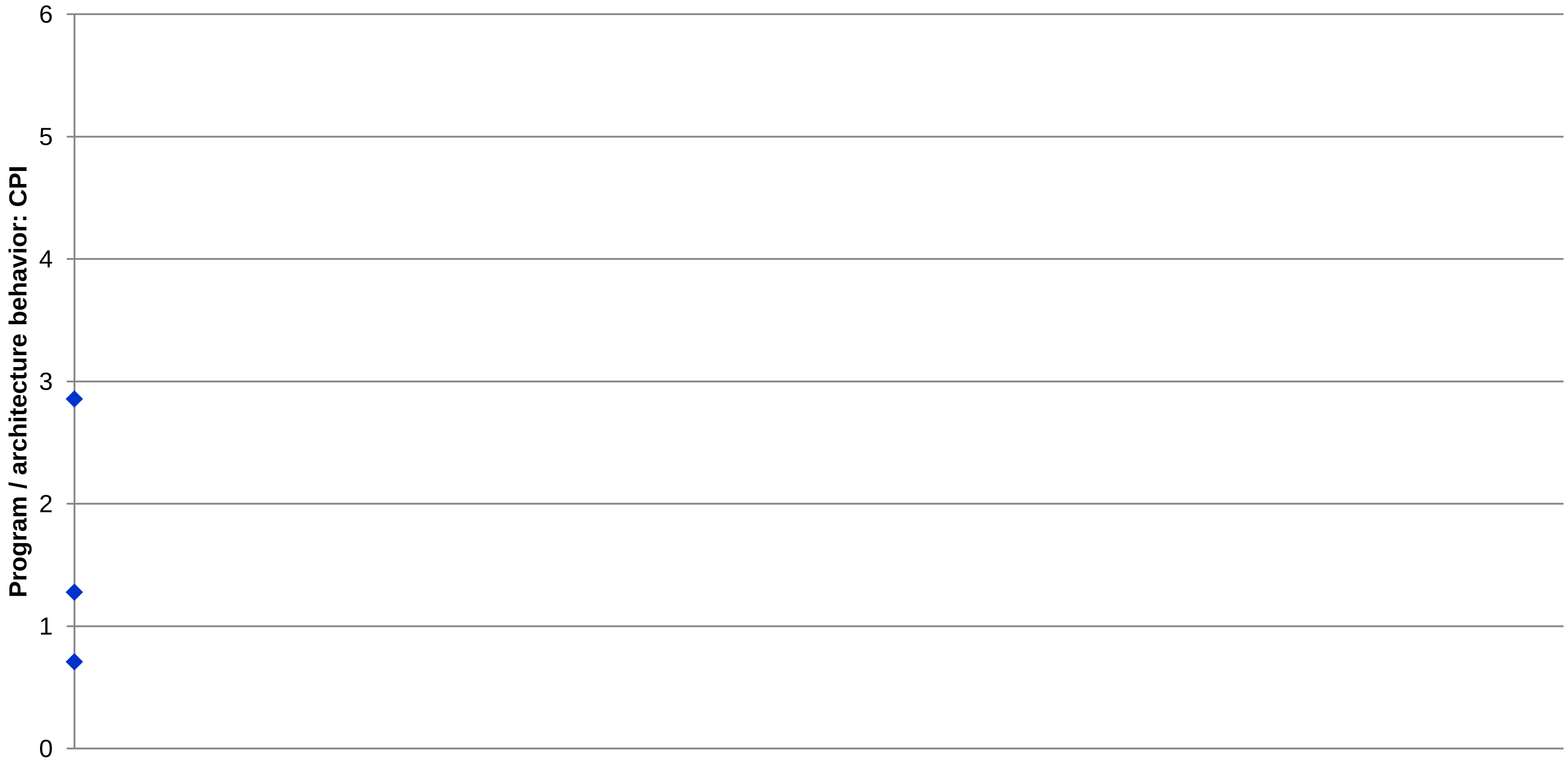
***Start from coarse-grain and gradually move to fine-grain level!***

Start coarse-grain decomposition of a system (detect coarse-grain effects first). Add universal learning modules.

# Example of characterizing/explaining behavior of computer systems

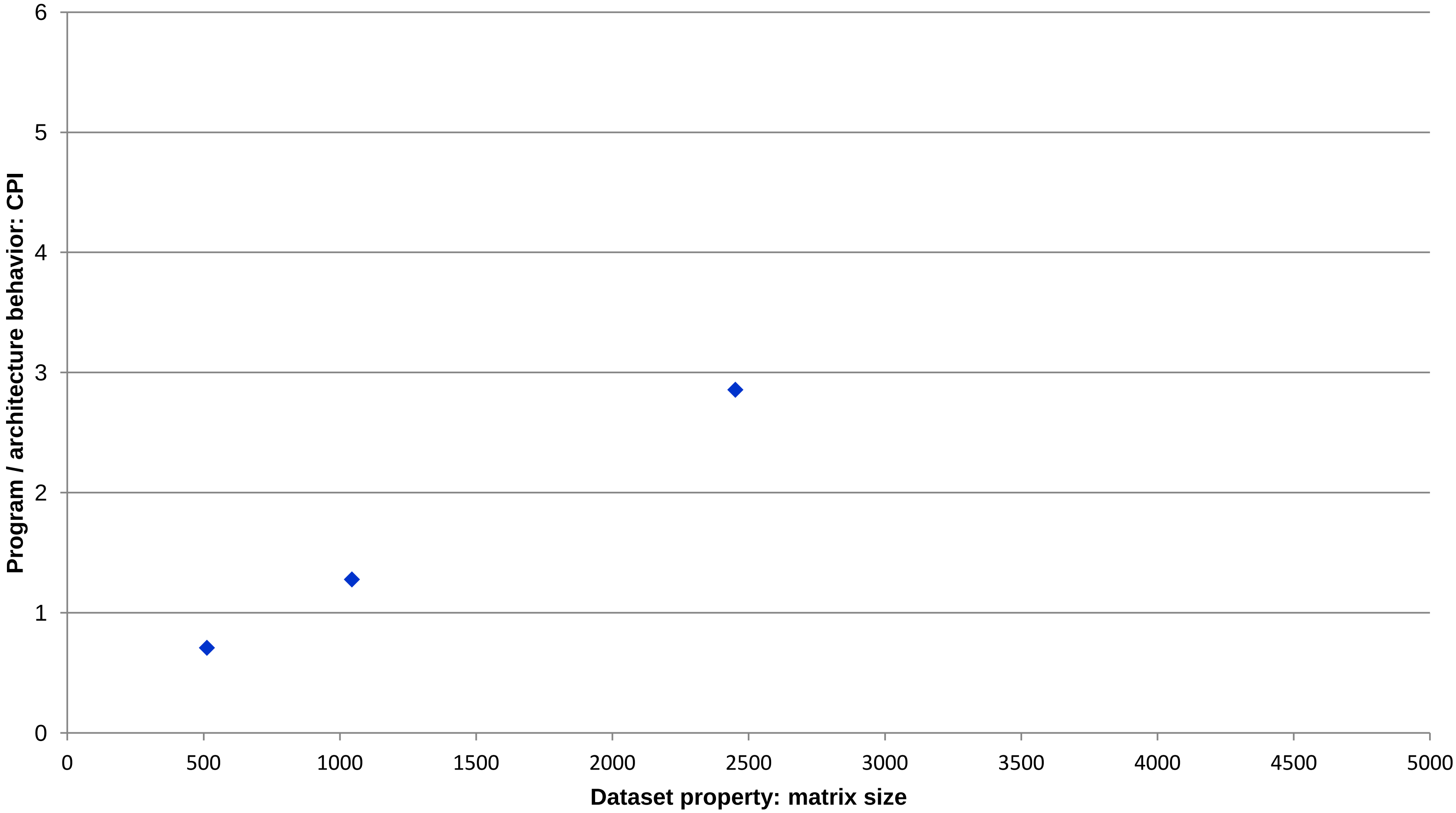
How we can explain the following observations for some piece of code ("codelet object")?

(LU-decomposition codelet, Intel Nehalem)



# Example of characterizing/explaining behavior of computer systems

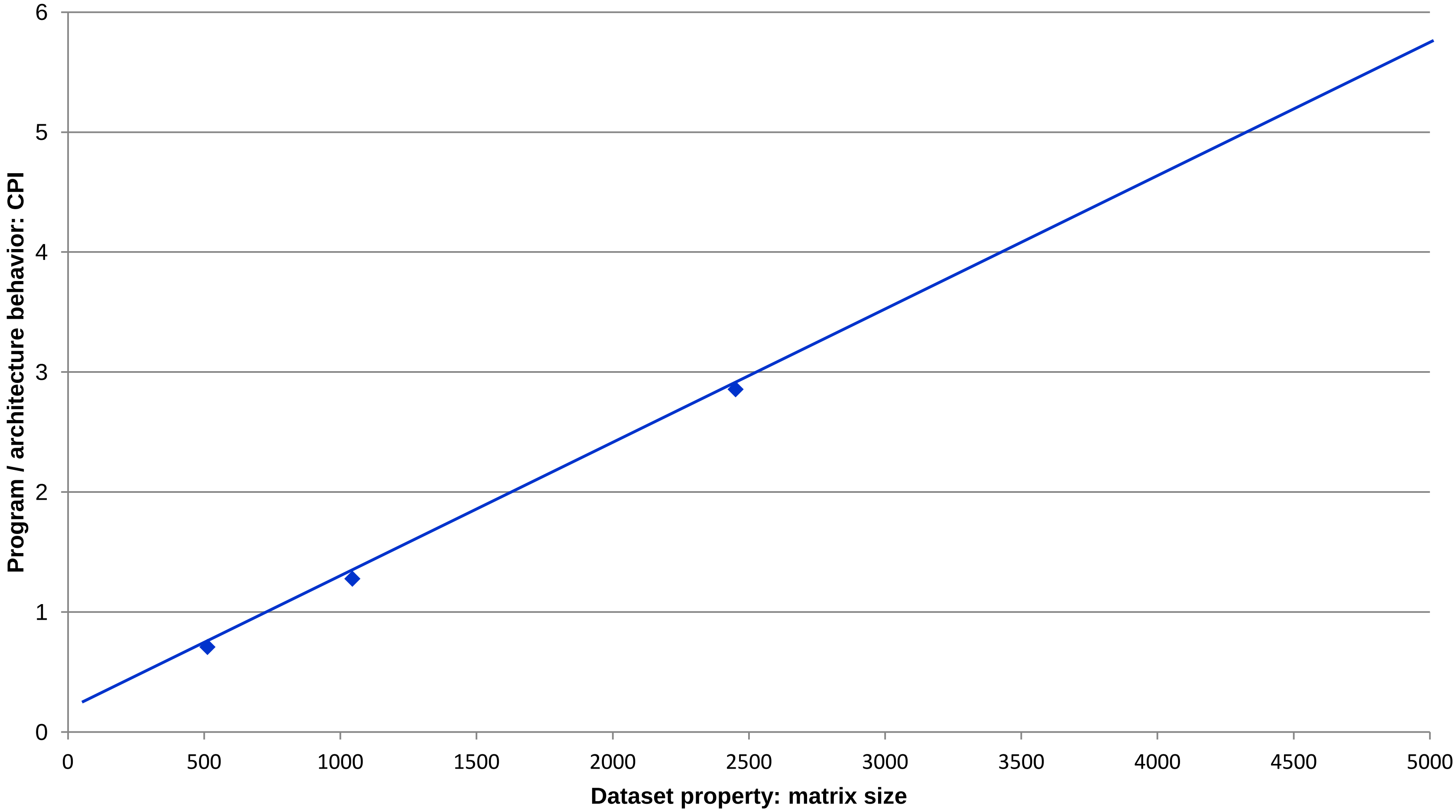
Add 1 property: matrix size



# Example of characterizing/explaining behavior of computer systems

Try to build a model to correlate objectives (CPI) and features (matrix size).

Start from simple models: linear regression (detect coarse grain effects)

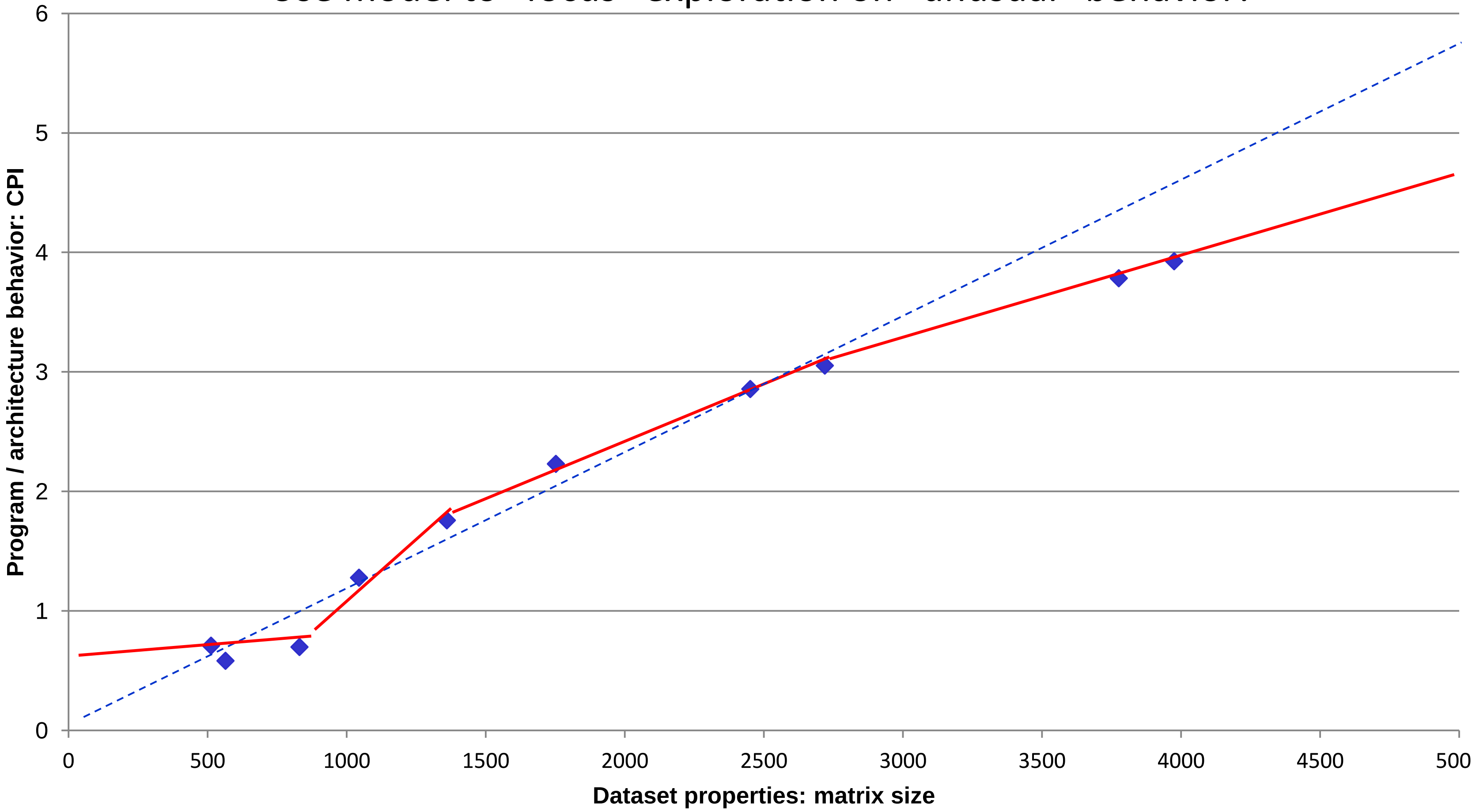


# Example of characterizing/explaining behavior of computer systems

If more observations, validate model and detect discrepancies!

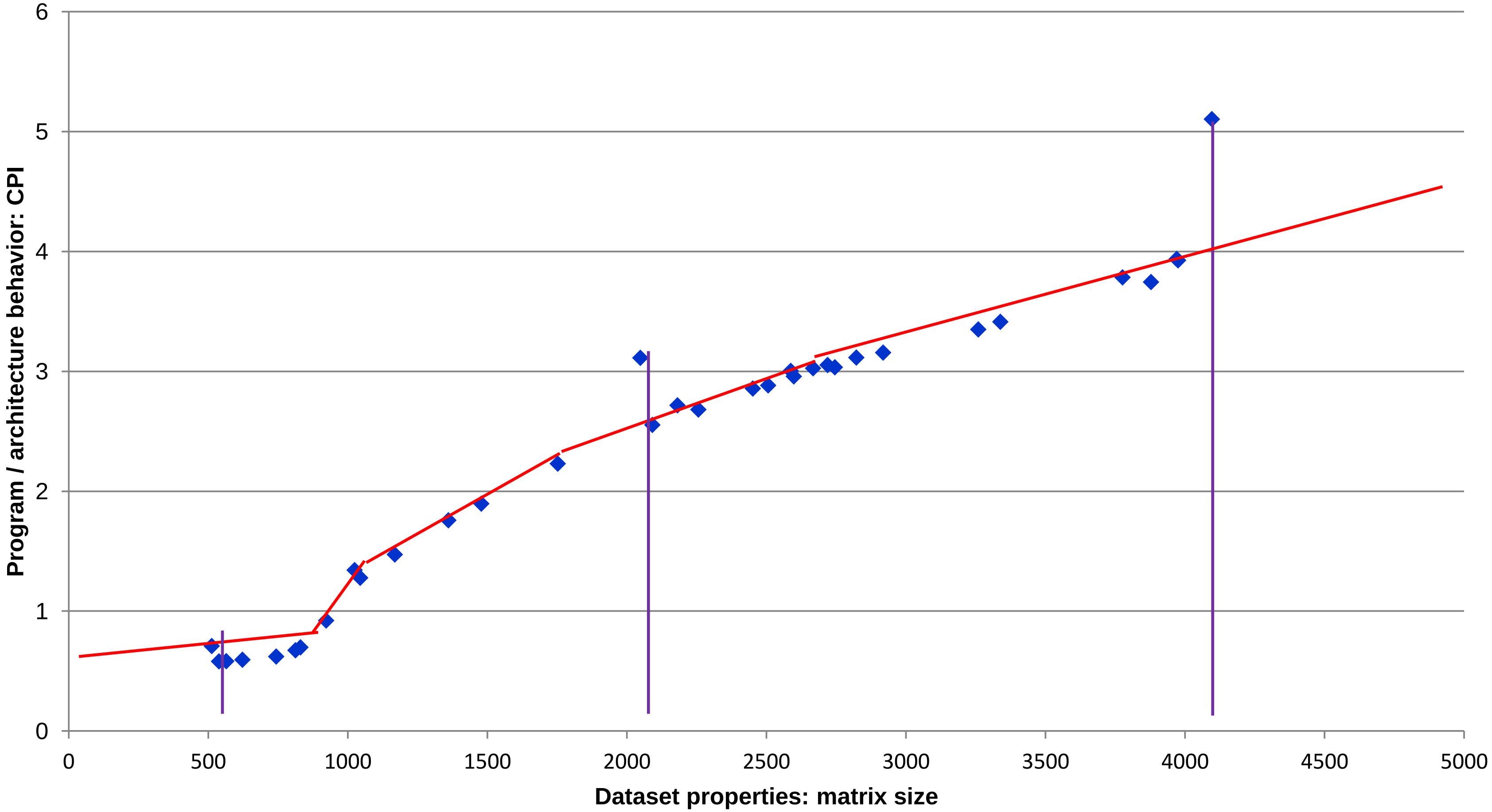
Continuously retrain models to fit new data!

Use model to “focus” exploration on “unusual” behavior!



# Example of characterizing/explaining behavior of computer systems

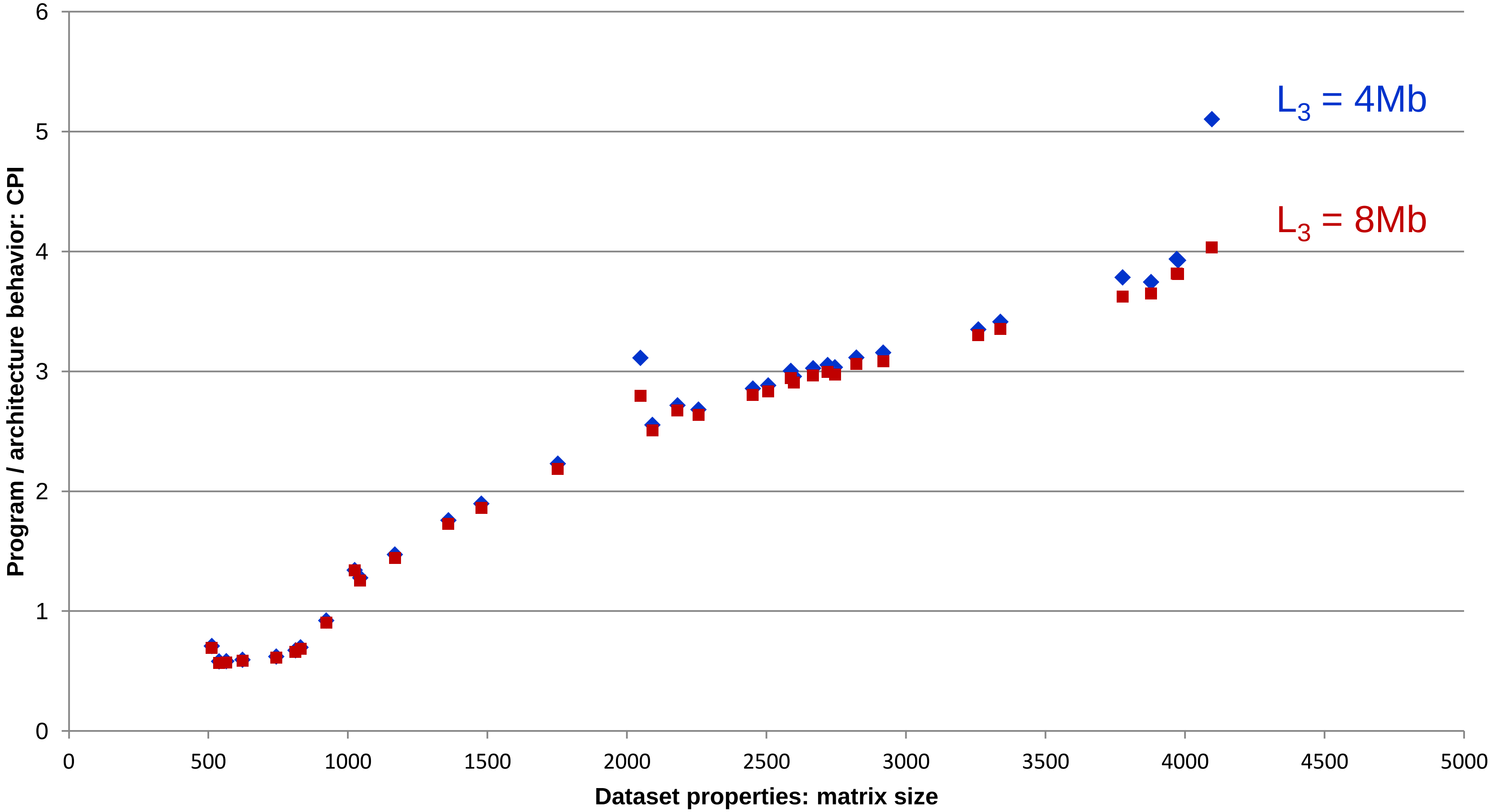
Gradually increase model complexity if needed (hierarchical modeling).
For example, detect fine-grain effects (singularities) and characterize them.



# Example of characterizing/explaining behavior of computer systems

Start adding more properties (one more architecture with twice bigger cache)!

Use automatic approach to correlate all objectives and features.



# Example of characterizing/explaining behavior of computer systems

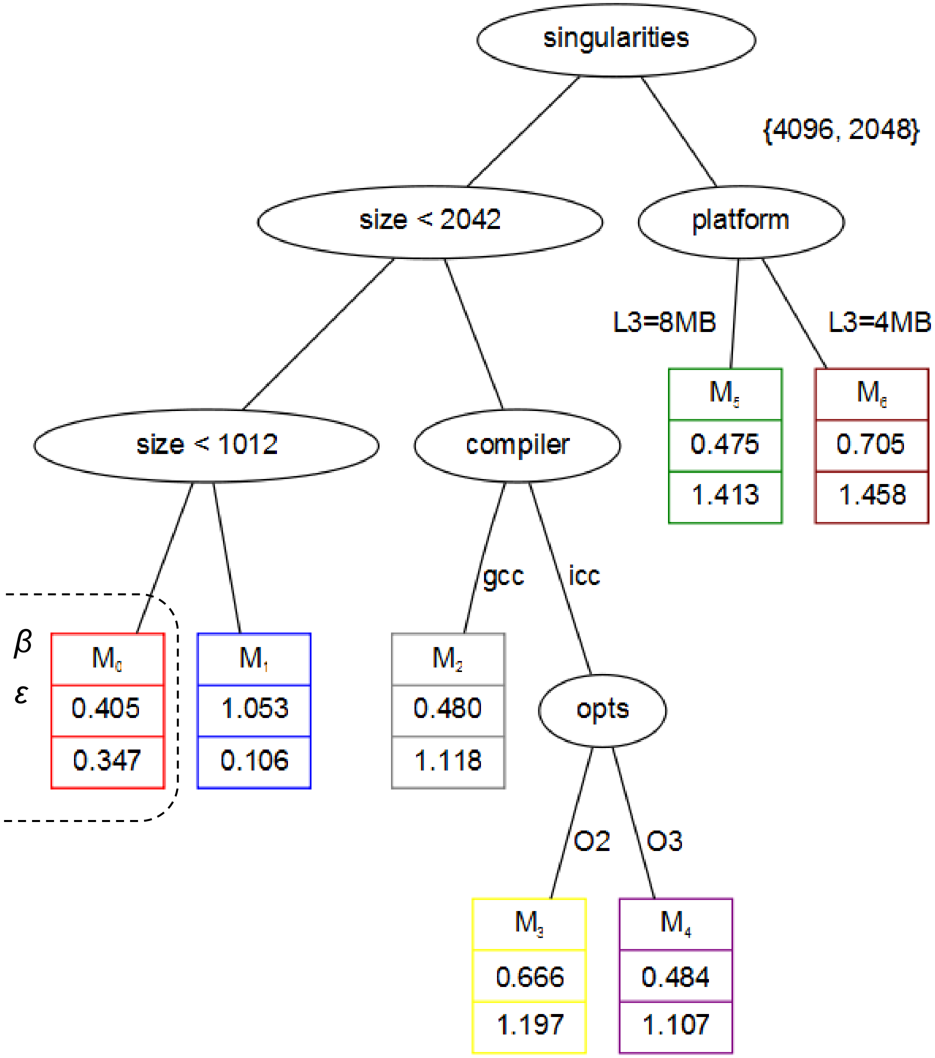
Continuously build and refine classification (decision trees for example) and predictive models on all collected data to improve predictions.

Continue exploring design and optimization spaces (evaluate different architectures, optimizations, compilers, etc.)

Focus exploration on unexplored areas, areas with high variability or with high mispredict rate of models

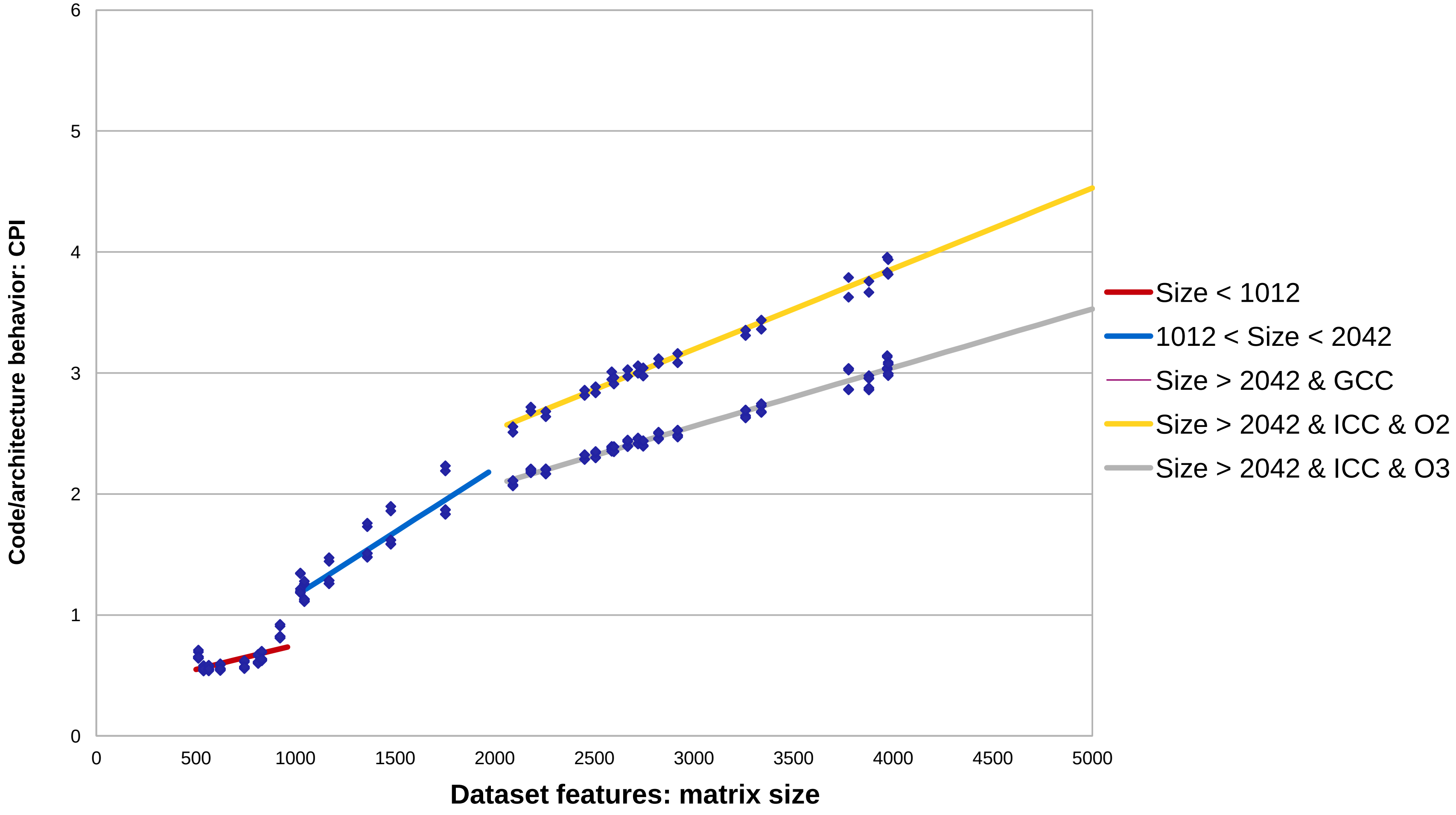
**cM predictive model module**

CPI = $\varepsilon + 1000 \times \beta \times$ data size



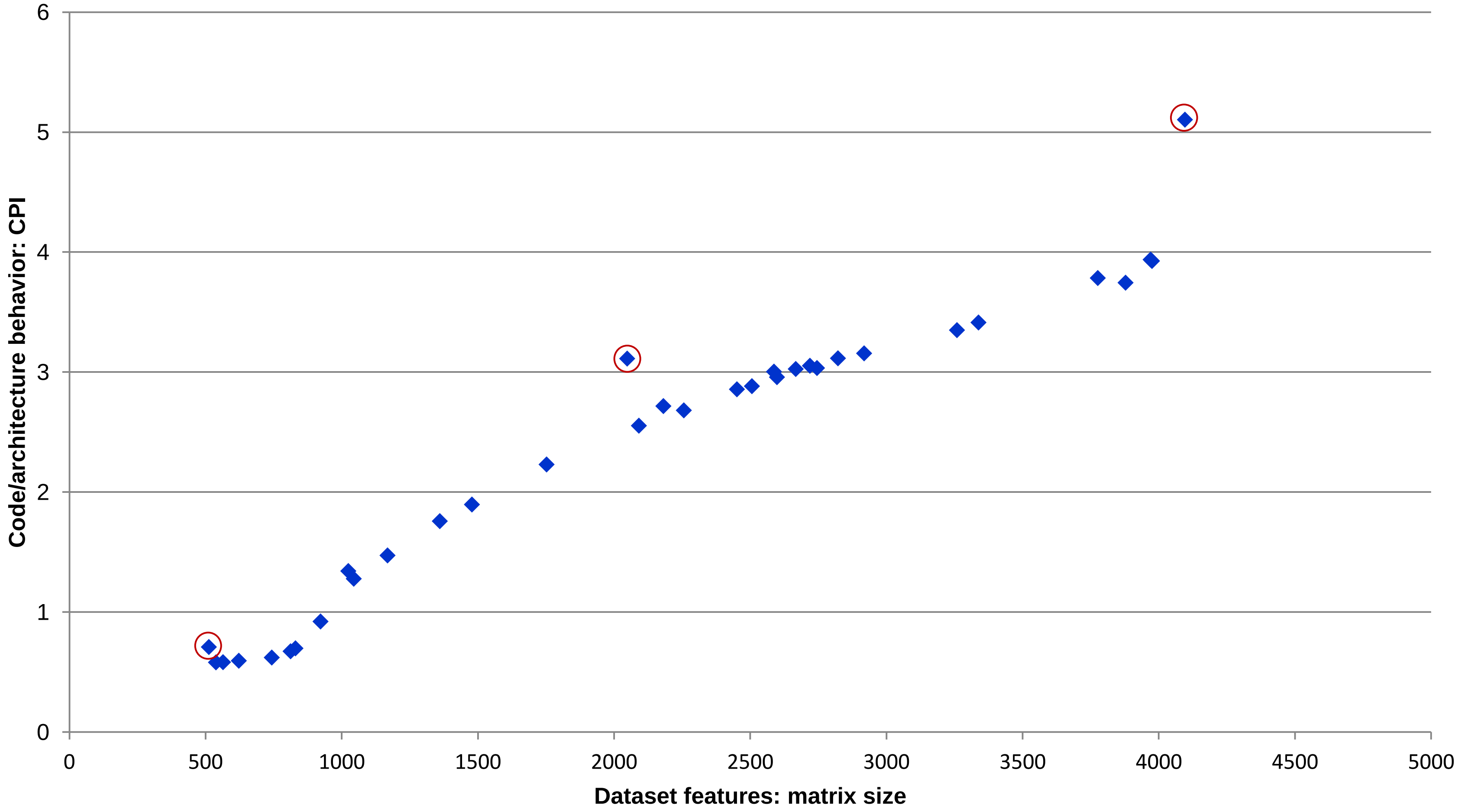
# Model optimization and data compaction

Optimize decision tree (many different algorithms)
Balance precision vs cost of modeling = ROI (coarse-grain vs fine-grain effects)
Compact data on-line before sharing with other users!



# Extensible and collaborative advice system

Collaboratively and continuously add expert advices or automatic optimizations.



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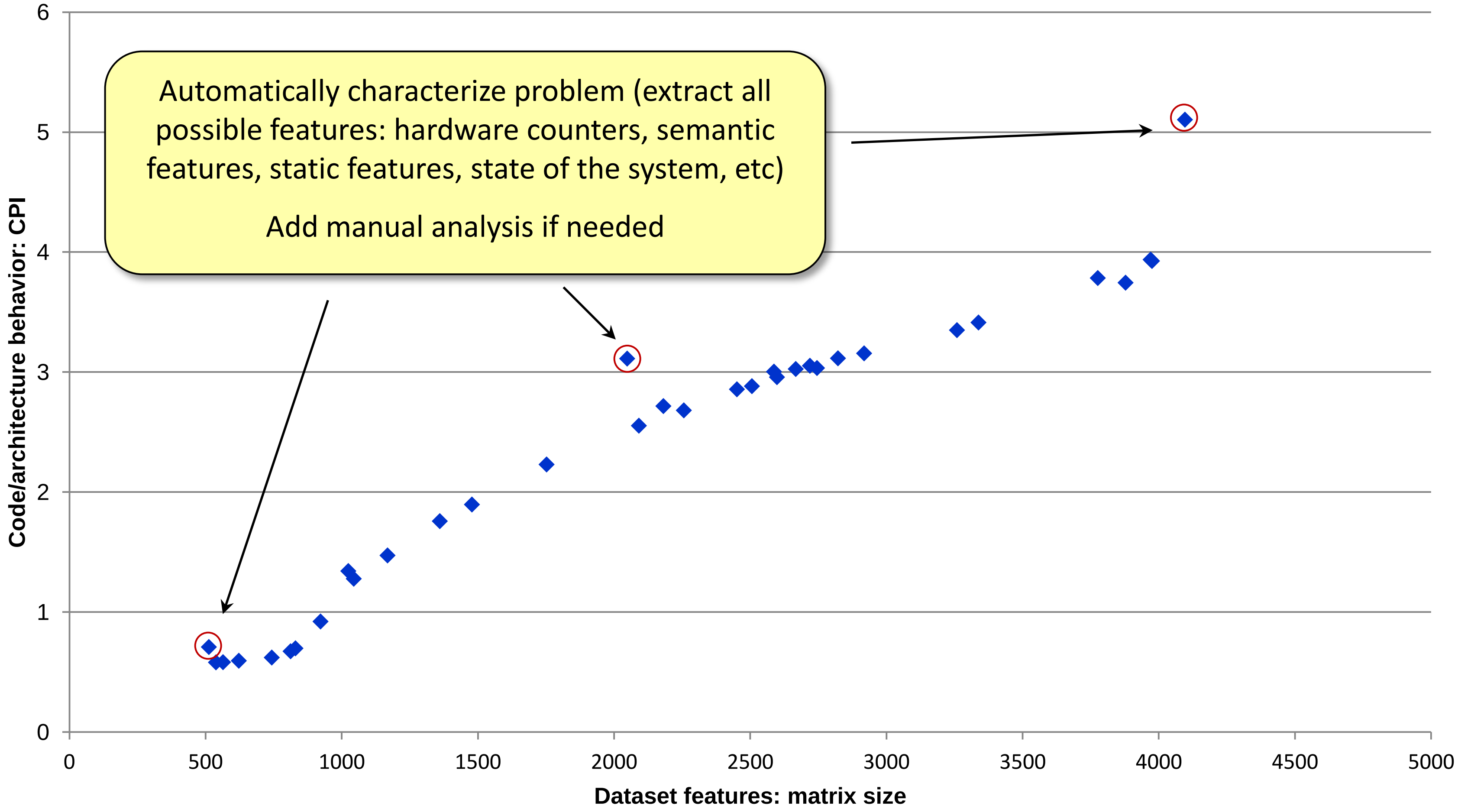

Automatically characterize problem (extract all possible features: hardware counters, semantic features, static features, state of the system, etc)

Add manual analysis if needed

# Extensible and collaborative advice system

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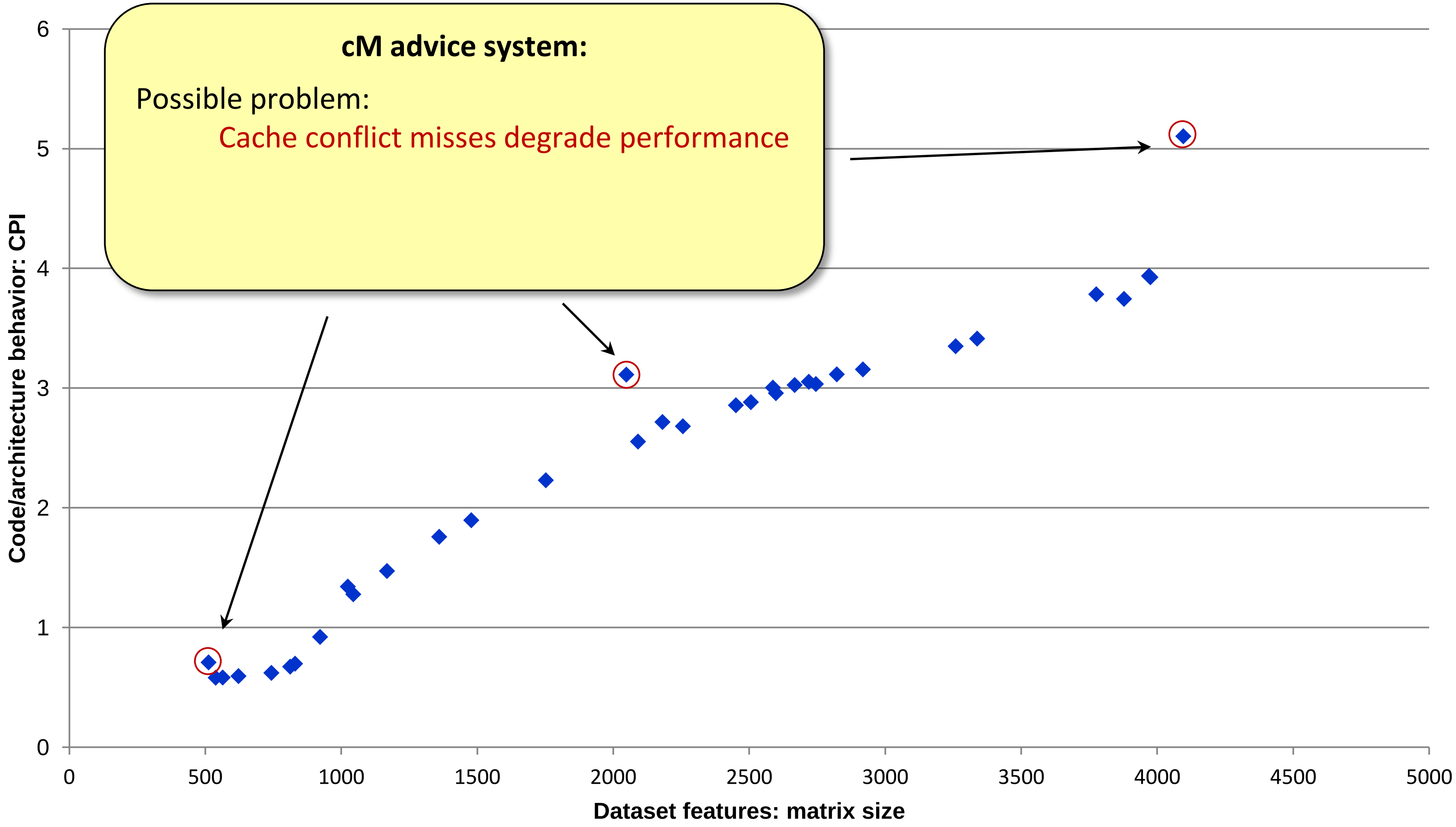

**cM advice system:**

Possible problem:

Cache conflict misses degrade performance

# Extensible and collaborative expert system

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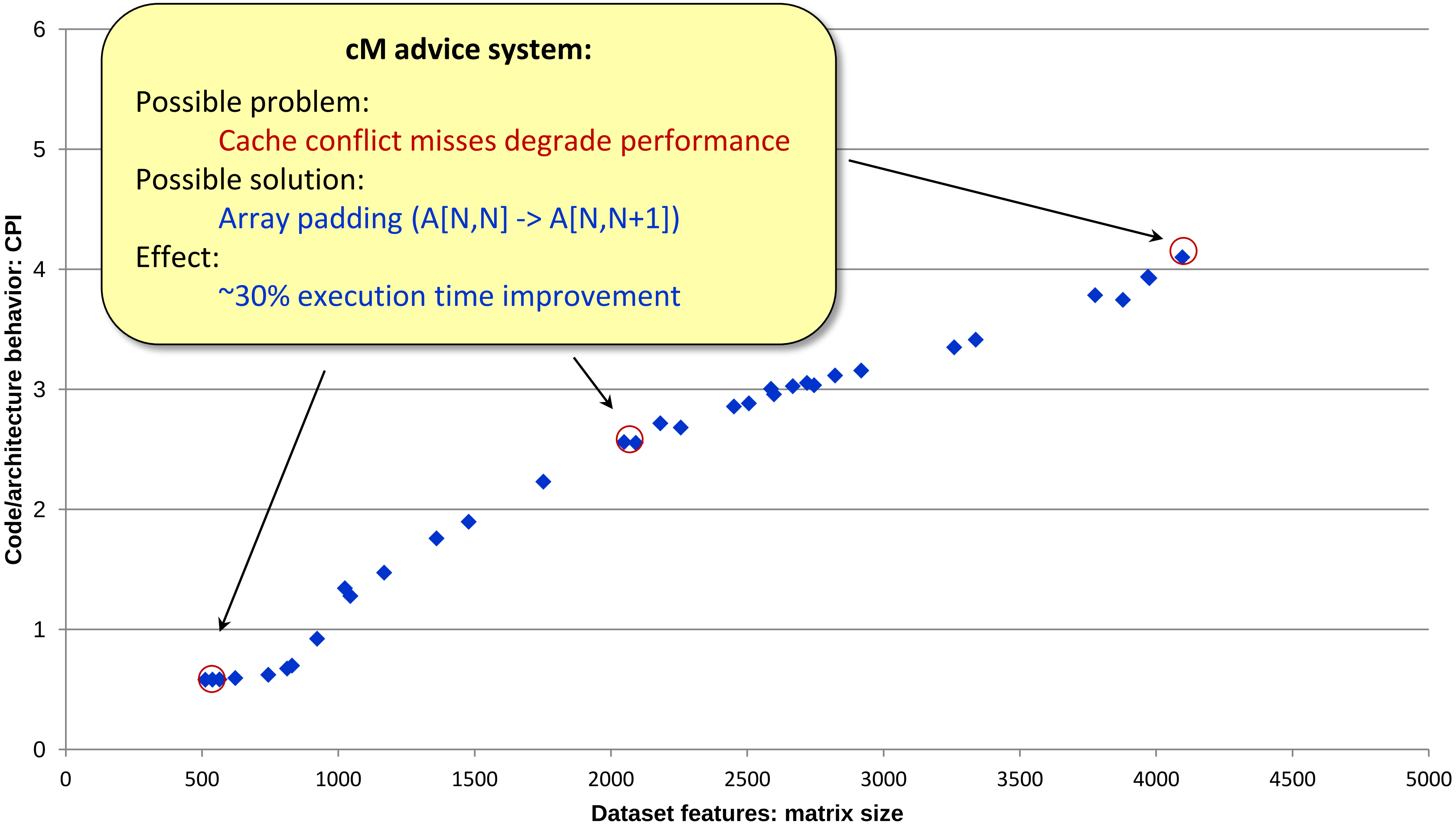


**cM advice system:**

Possible problem:

Cache conflict misses degrade performance

Possible solution:

Array padding (A[N,N] -> A[N,N+1])

Effect:

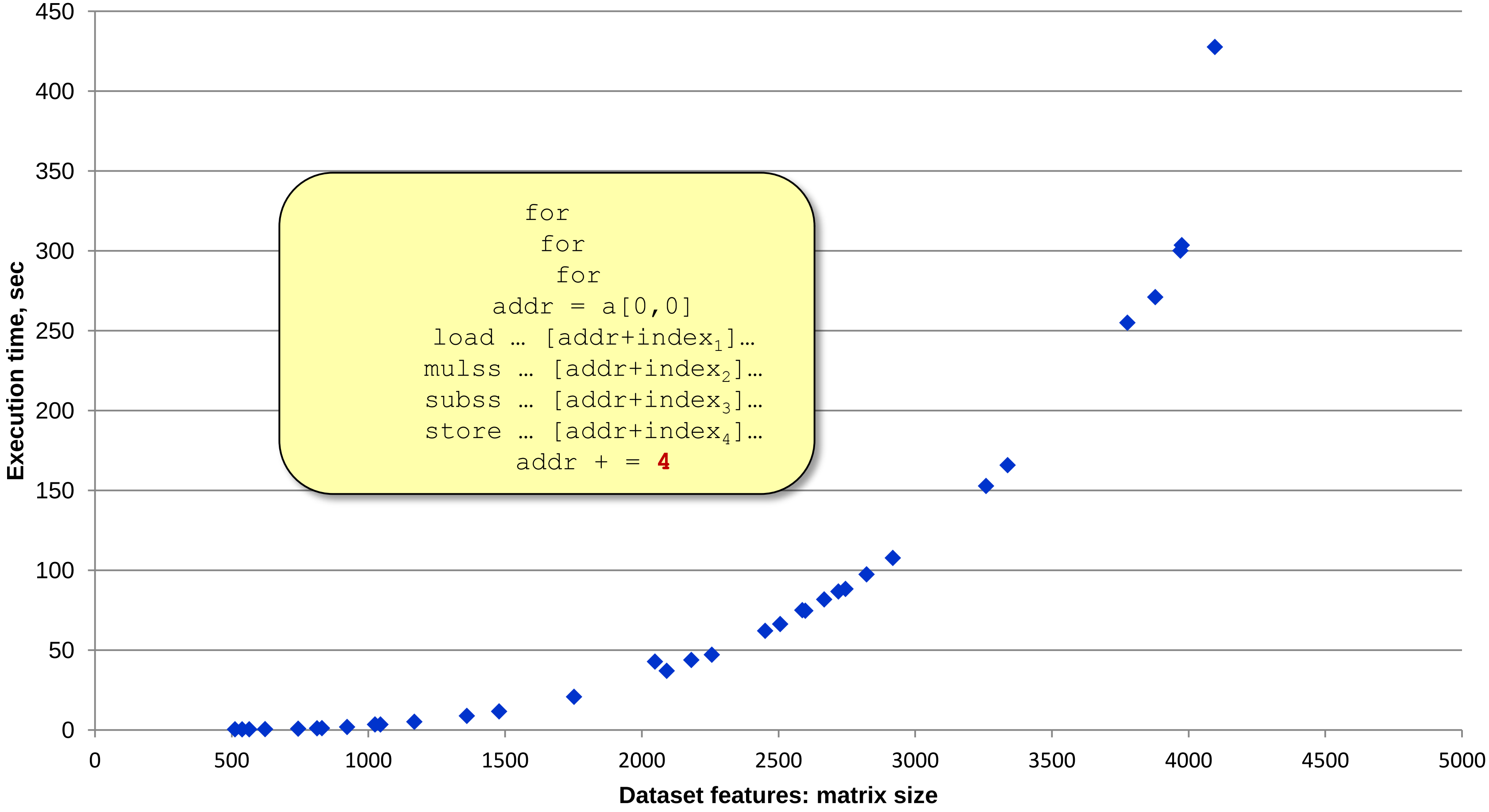
~30% execution time improvement

# System reaction to code changes: physicist's view

Add dynamic memory characterization through semantically non-equivalent modifications.

*For example, convert all array accesses to scalars to detect balance between CPU/memory accesses.*

Intentionally change/break semantics to observe reaction in terms of performance/power etc!



```
for
 for
  for
addr = a[0,0]
load … [addr+index_1]…
mulss … [addr+index_2]…
subss … [addr+index_3]…
store … [addr+index_4]…
addr + = 4
```

*Grigori Fursin, Mike O'Boyle, Olivier Temam, and Gregory Watts.* ***Fast and Accurate Method for Determining a Lower Bound on Execution Time.*** *Concurrency Practice and Experience, 16(2-3), pages 271-292, 2004*

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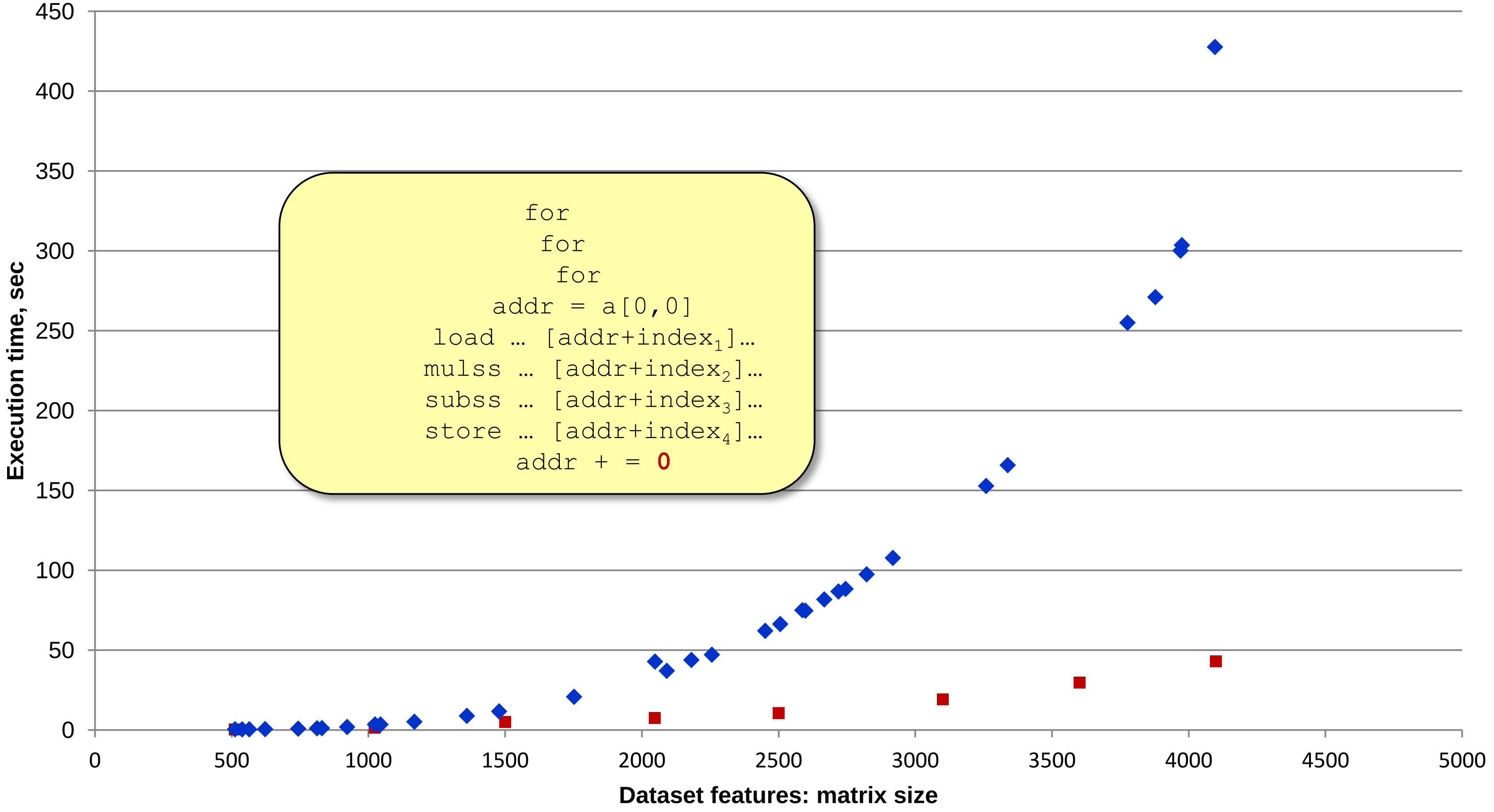

```
        for
         for
          for
      addr = a[0,0]
  load … [addr+index1]…
 mulss … [addr+index2]…
 subss … [addr+index3]…
 store … [addr+index4]…
     addr + = 0
```

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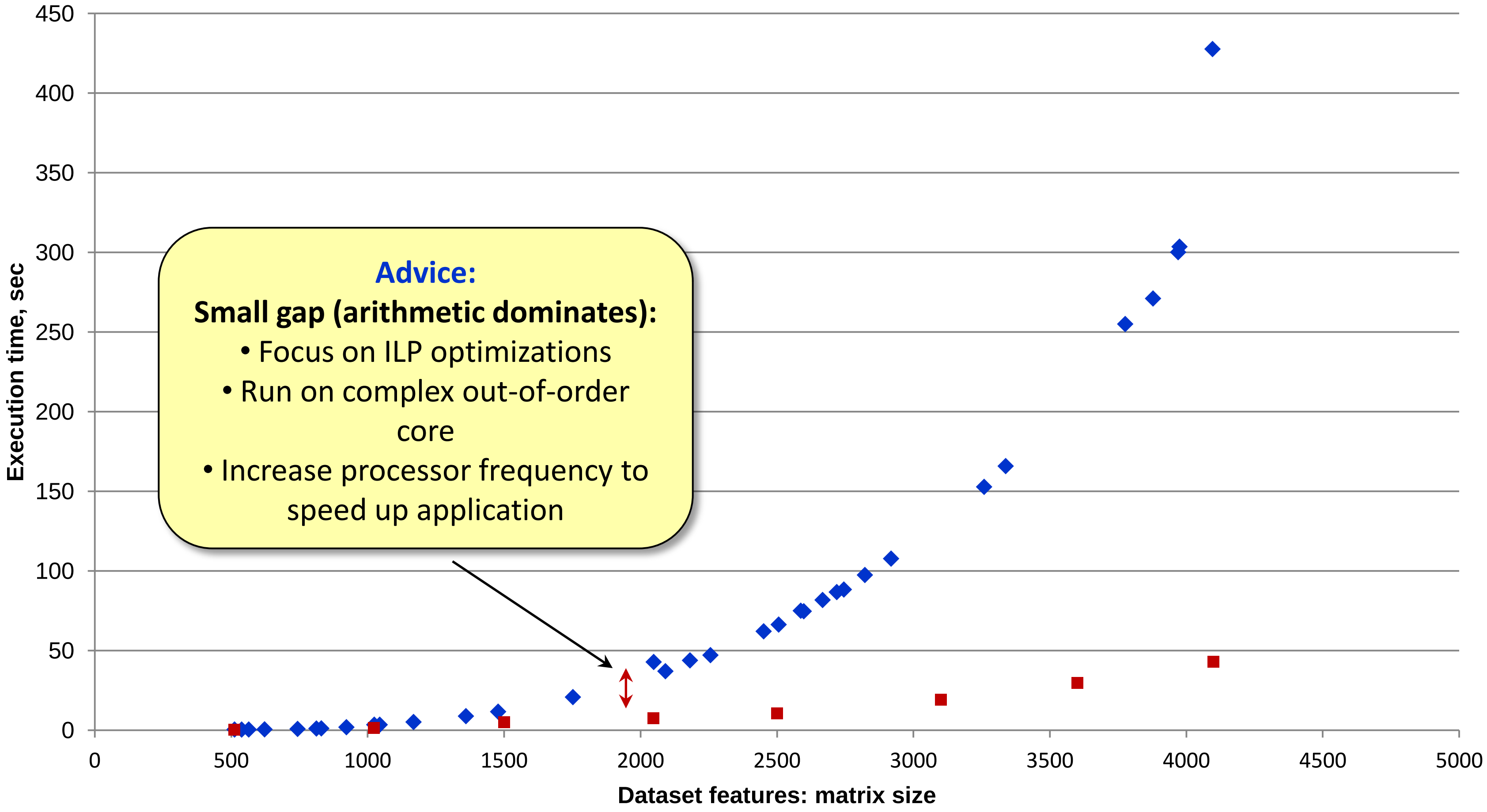
# System reaction to code changes: physicist's view

Extended CTI advices based on additional information in the repository!

Focus optimizations to speed up search: which/where?



**Advice:**

**Small gap (arithmetic dominates):**

- Focus on ILP optimizations
- Run on complex out-of-order core
- Increase processor frequency to speed up application

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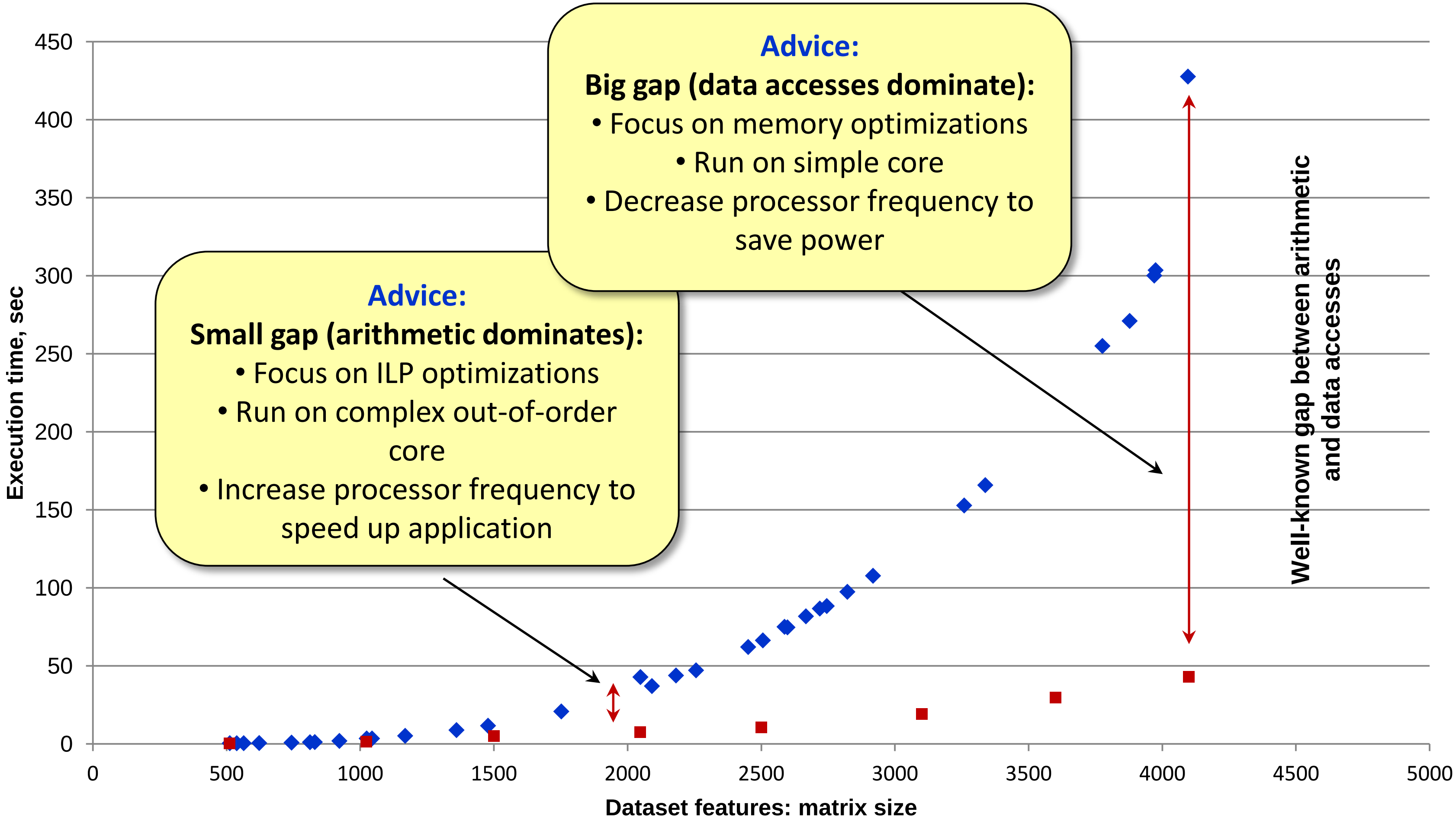

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**Advice:**

**Big gap (data accesses dominate):**

- Focus on memory optimizations
- Run on simple core
- Decrease processor frequency to save power

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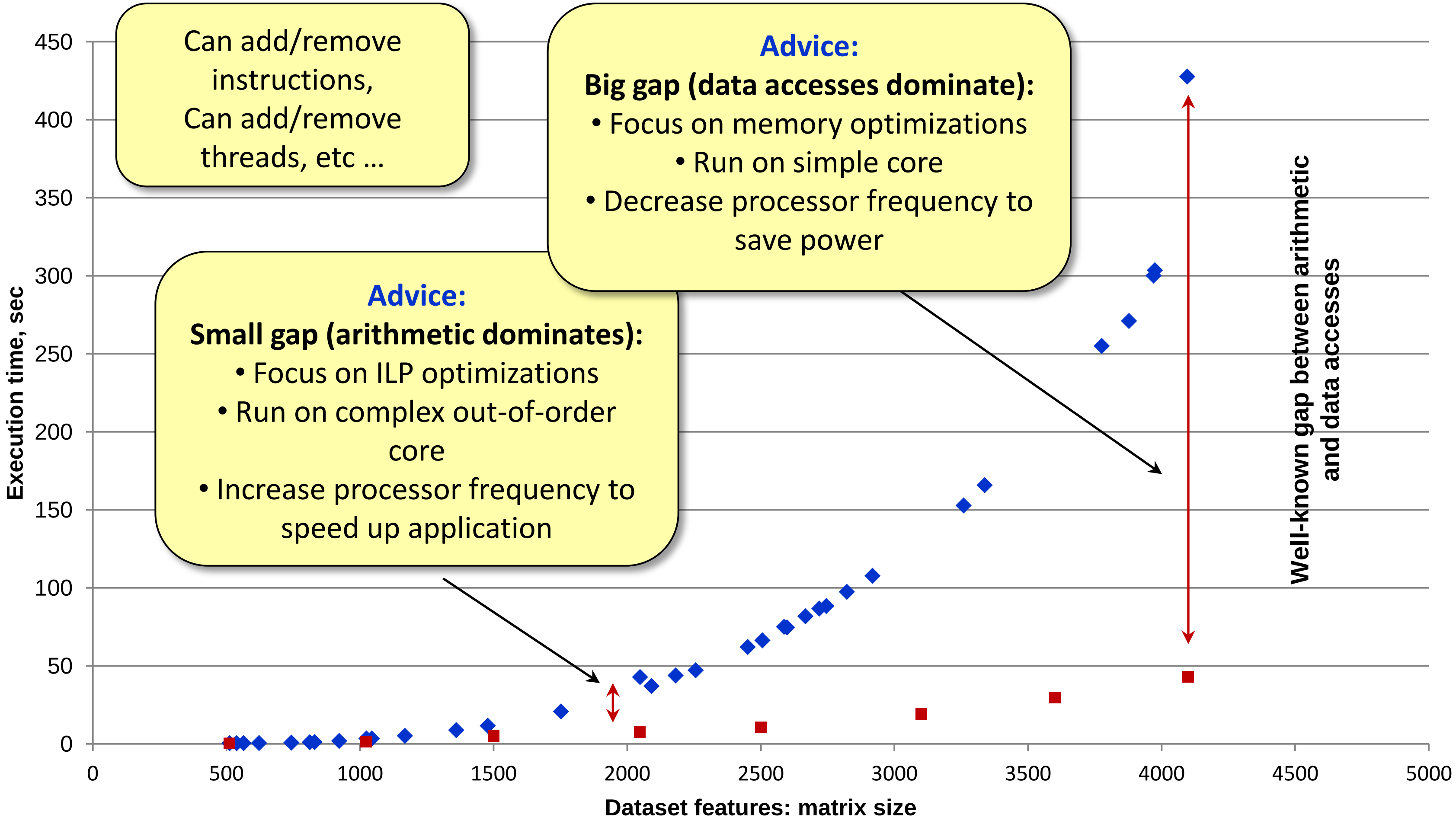

Can add/remove instructions, Can add/remove threads, etc ...

**Advice:**

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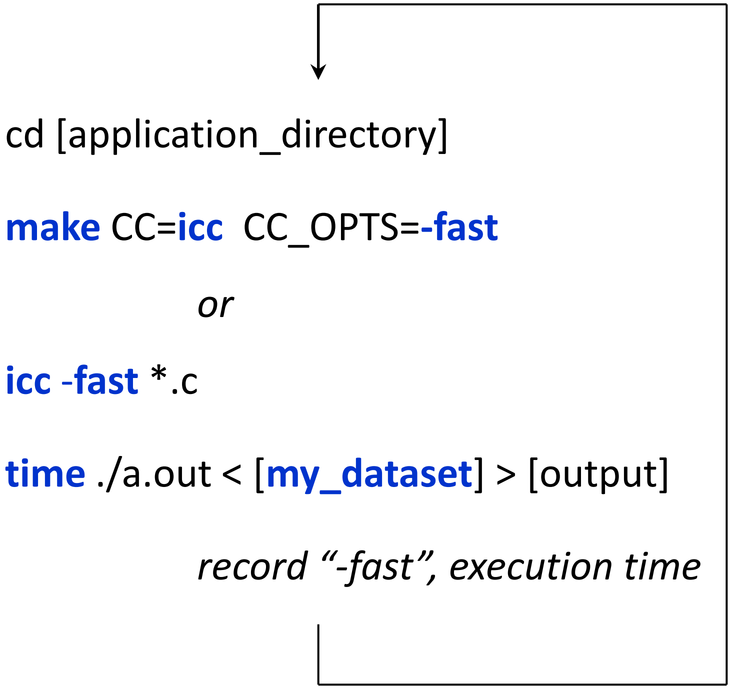
# Implementation in open-source cTuning$_1$ framework



```
cd [application_directory]

make CC=icc  CC_OPTS=-fast

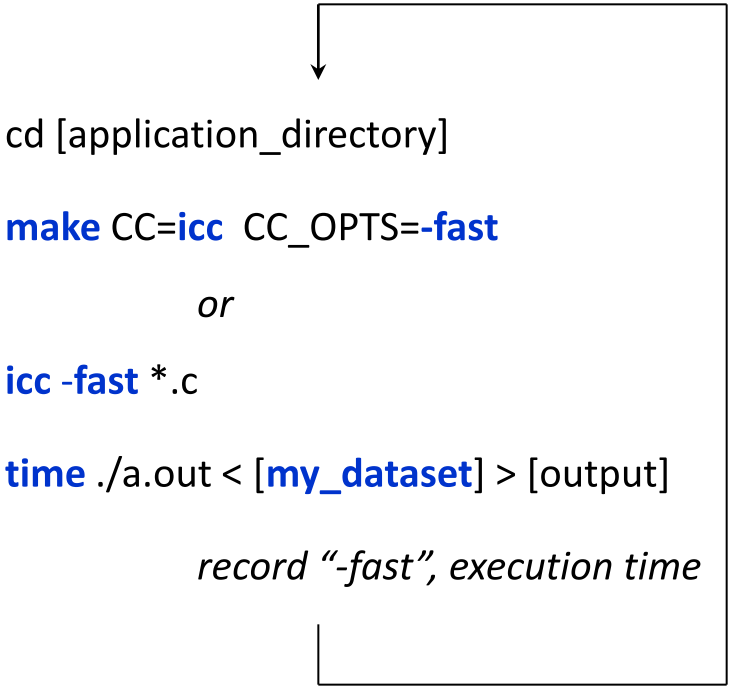
          or

icc -fast *.c

time ./a.out < [my_dataset] > [output]
```

*record "-fast", execution time*

# Implementation in open-source cTuning$_1$ framework



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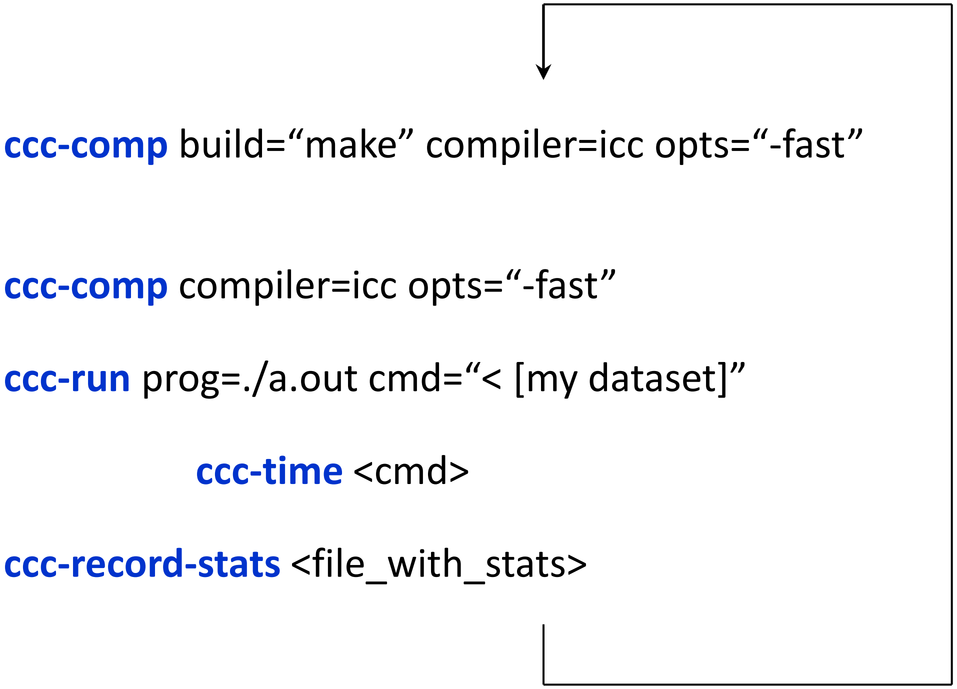
```



```
ccc-comp build=“make” compiler=icc opts=“-fast”


ccc-comp compiler=icc opts=“-fast”

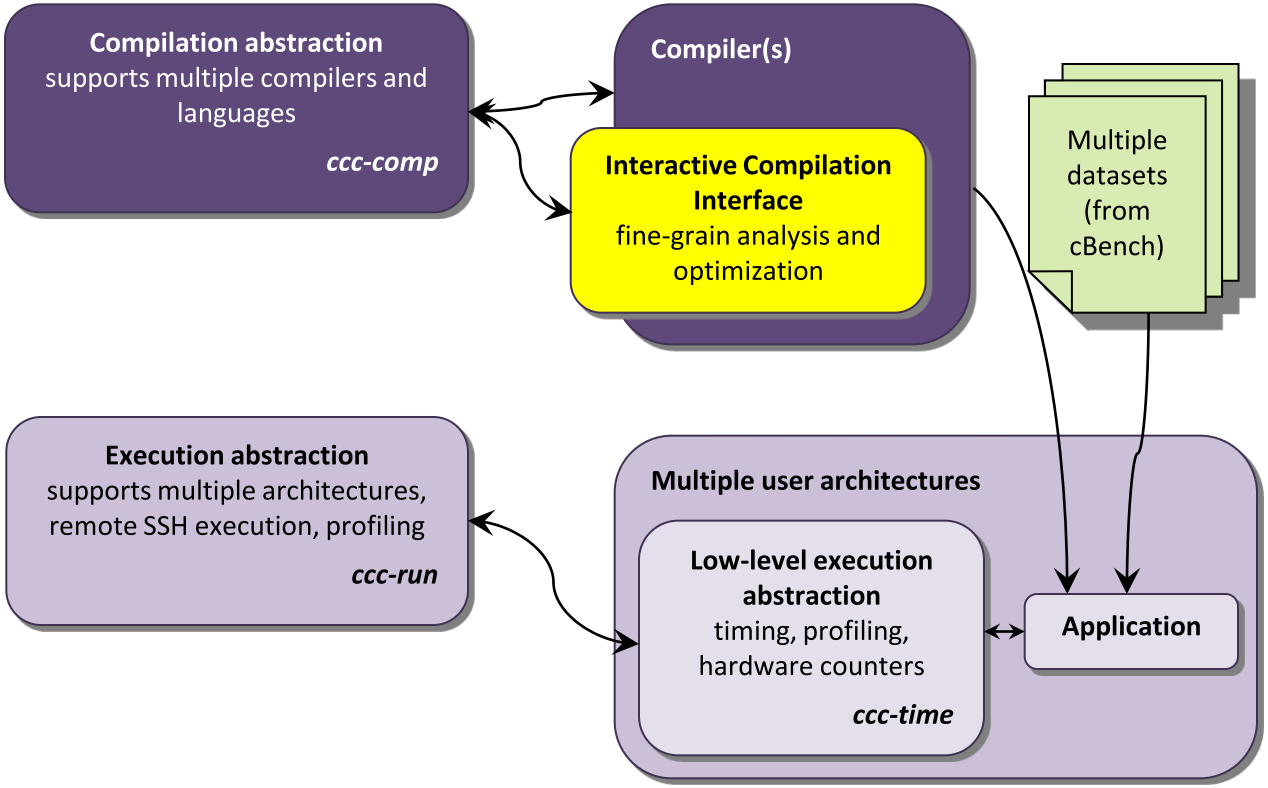
ccc-run prog=./a.out cmd=“< [my dataset]”

              ccc-time <cmd>

ccc-record-stats <file_with_stats>
```

- *Low level platform-dependent plugins in C*
- *Communication through text file or directly through MySQL database*
- *High level platform-independent exploration or analysis plugins in PHP*
- *Web services at cTuning.org as plugins in PHP*

# Implementation in open-source cTuning$_1$ framework



**Compilation abstraction**
supports multiple compilers and languages

***ccc-comp***

**Compiler(s)**

**Interactive Compilation Interface**
fine-grain analysis and optimization

Multiple datasets (from cBench)

**Execution abstraction**
supports multiple architectures, remote SSH execution, profiling

***ccc-run***

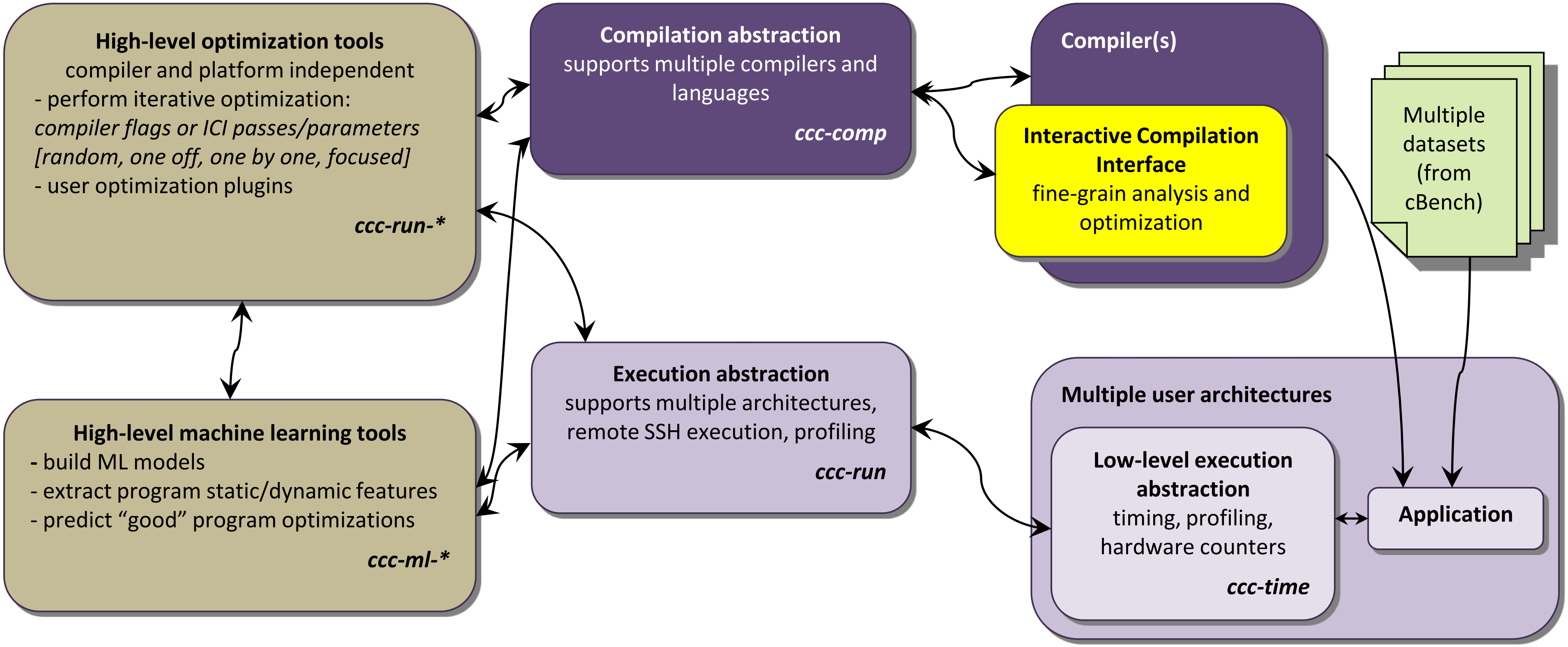
**Multiple user architectures**

**Low-level execution abstraction**
timing, profiling, hardware counters

***ccc-time***

**Application**

# Implementation in open-source cTuning[1] framework



**High-level optimization tools**
compiler and platform independent
- perform iterative optimization:
*compiler flags or ICI passes/parameters*
*[random, one off, one by one, focused]*
- user optimization plugins

***ccc-run-****

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Multiple datasets (from cBench)

**High-level machine learning tools**
- build ML models
- extract program static/dynamic features
- predict "good" program optimizations

***ccc-ml-****

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***ccc-run***

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***ccc-time***

**Application**

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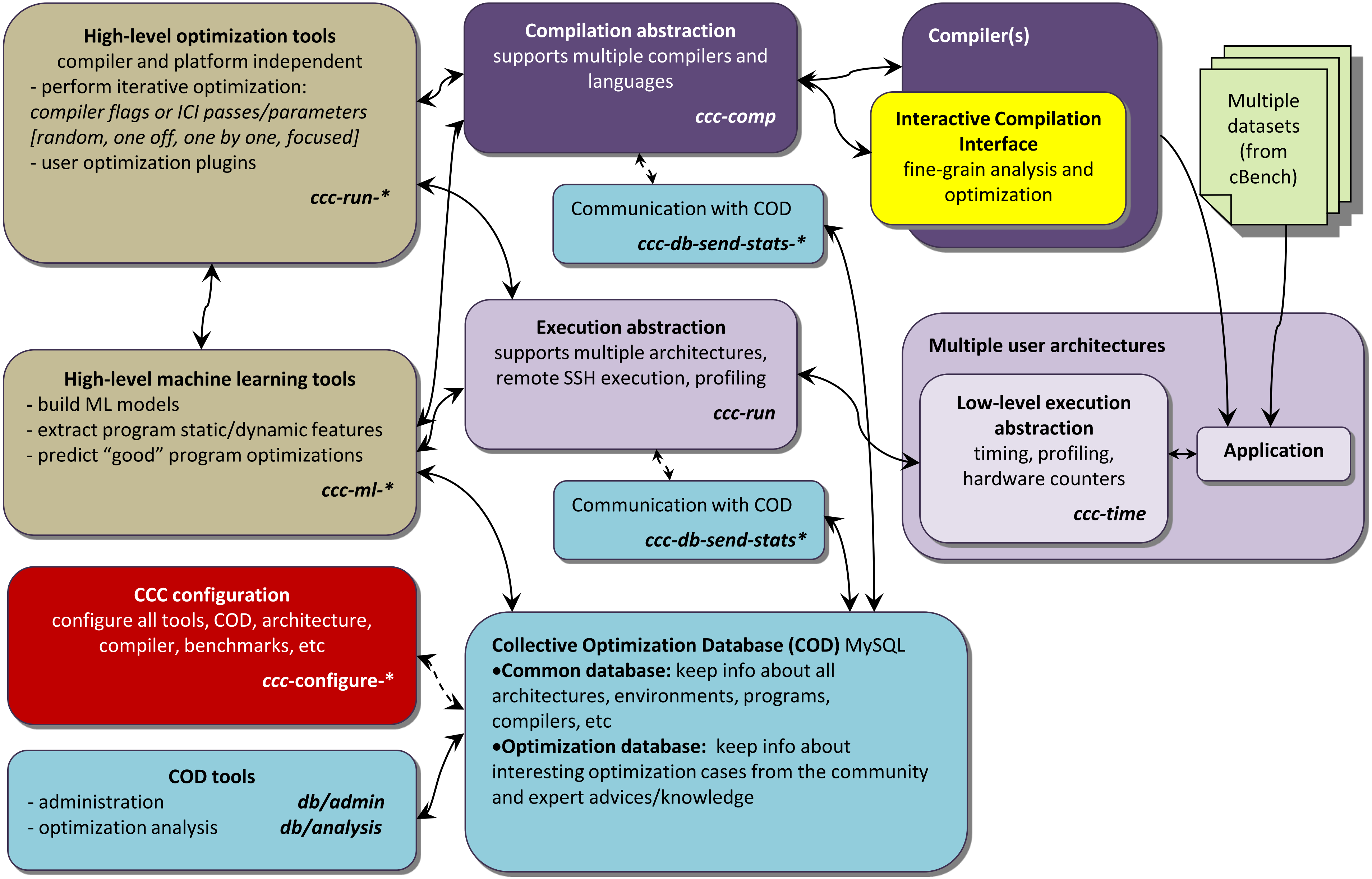

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Communication with COD
***ccc-db-send-stats-****

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***ccc-ml-****

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***ccc-run***

**Multiple user architectures**

**Low-level execution abstraction**
timing, profiling, hardware counters
***ccc-time***

**Application**

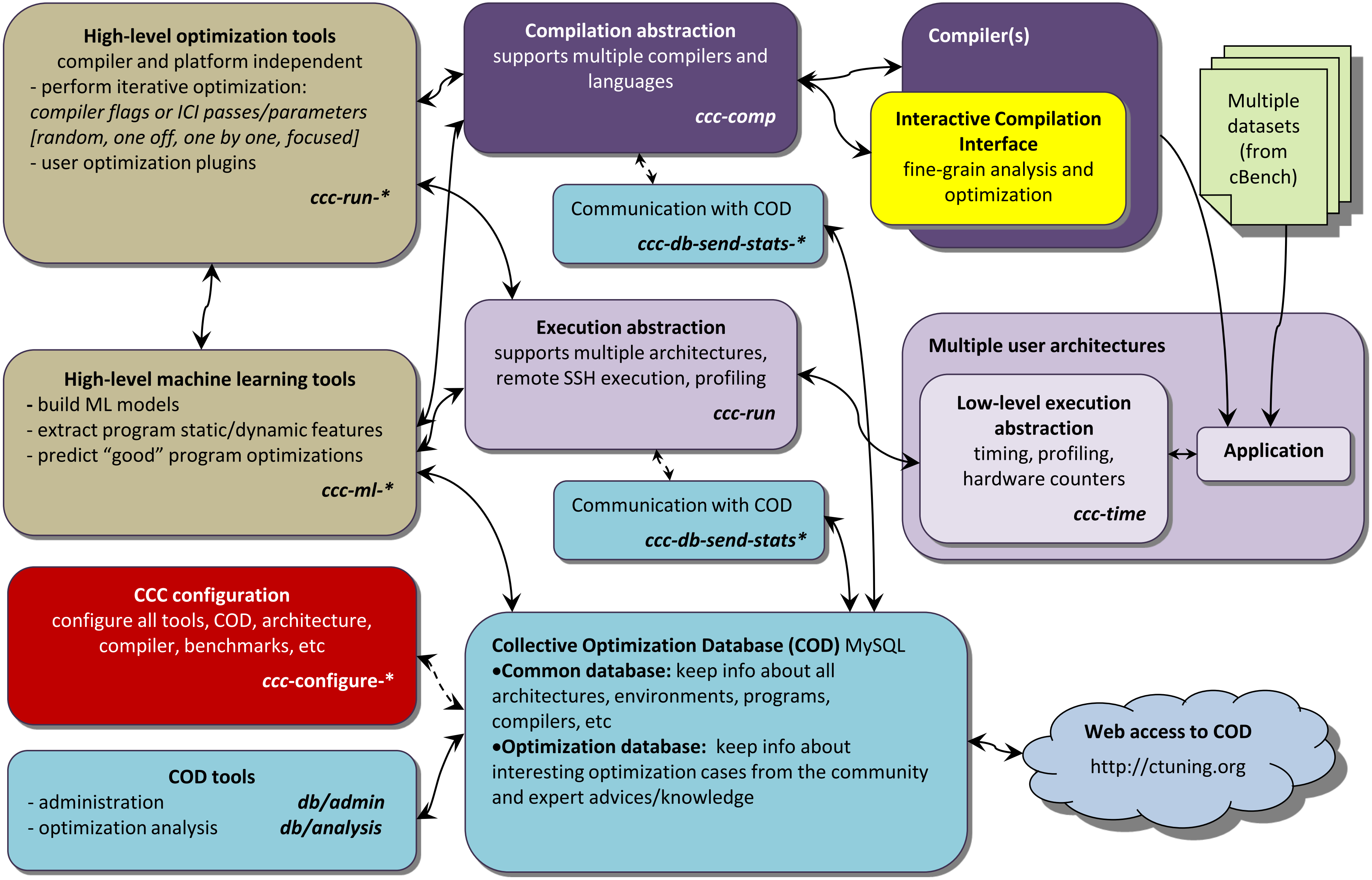
Communication with COD
***ccc-db-send-stats****

**CCC configuration**
configure all tools, COD, architecture, compiler, benchmarks, etc
***ccc*-configure-****

**Collective Optimization Database (COD)** MySQL
- **Common database:** keep info about all architectures, environments, programs, compilers, etc
- **Optimization database:** keep info about interesting optimization cases from the community and expert advices/knowledge

**COD tools**
- administration ***db/admin***
- optimization analysis ***db/analysis***

# Implementation in open-source cTuning$_1$ framework



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***ccc-ml-****

**Execution abstraction**
supports multiple architectures, remote SSH execution, profiling
***ccc-run***

**Multiple user architectures**

**Low-level execution abstraction**
timing, profiling, hardware counters
***ccc-time***

**Application**

Communication with COD
***ccc-db-send-stats****

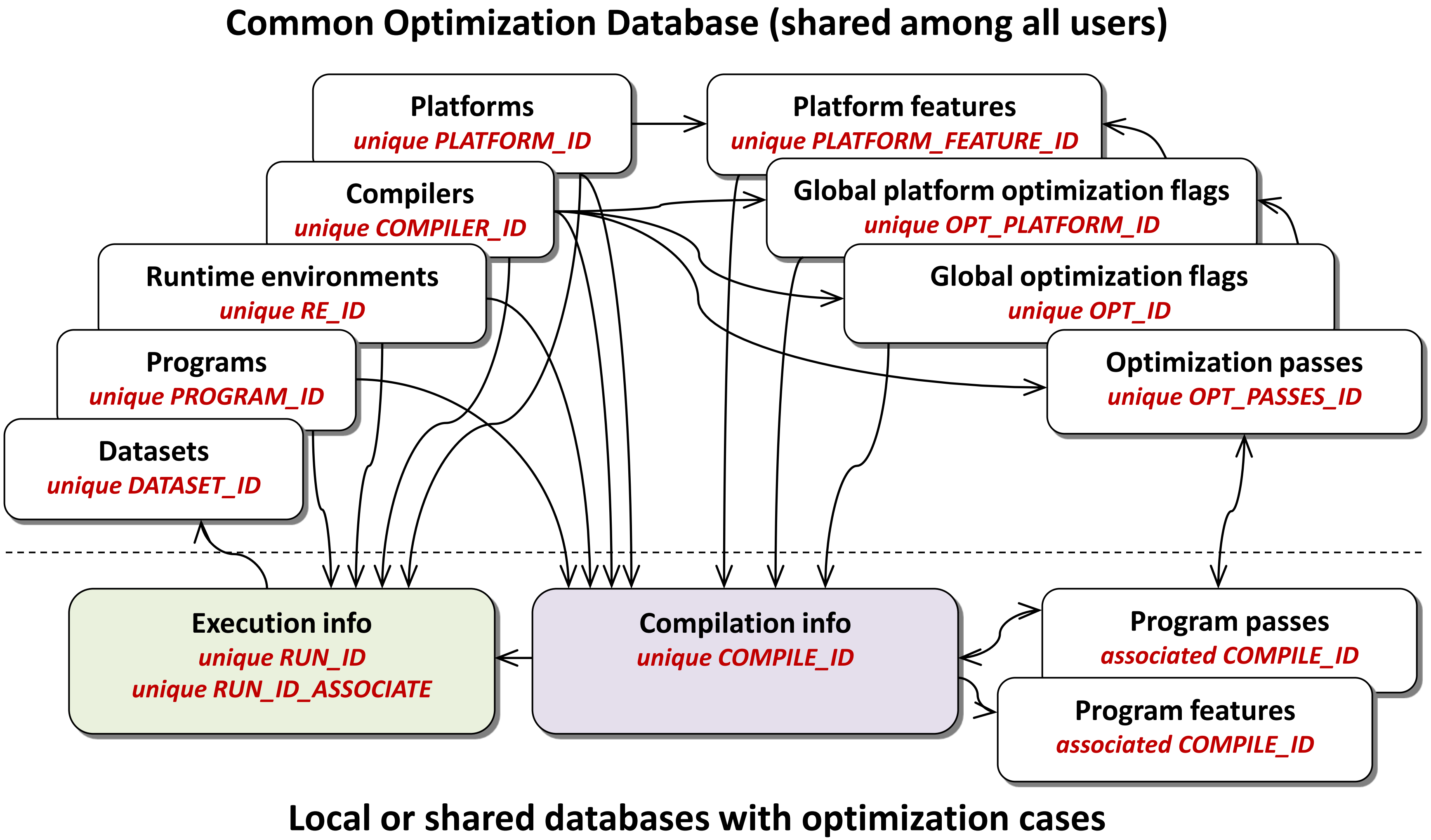
**CCC configuration**
configure all tools, COD, architecture, compiler, benchmarks, etc
***ccc*-configure-***

**Collective Optimization Database (COD)** MySQL
•**Common database:** keep info about all architectures, environments, programs, compilers, etc
•**Optimization database:** keep info about interesting optimization cases from the community and expert advices/knowledge

**COD tools**
- administration ***db/admin***
- optimization analysis ***db/analysis***

**Web access to COD**
http://ctuning.org

# MySQL-based Collective Optimization Database



Common Optimization Database (shared among all users)

Platforms
unique PLATFORM_ID

Platform features
unique PLATFORM_FEATURE_ID

Compilers
unique COMPILER_ID

Global platform optimization flags
unique OPT_PLATFORM_ID

Runtime environments
unique RE_ID

Global optimization flags
unique OPT_ID

Programs
unique PROGRAM_ID

Optimization passes
unique OPT_PASSES_ID

Datasets
unique DATASET_ID

Execution info
unique RUN_ID
unique RUN_ID_ASSOCIATE

Compilation info
unique COMPILE_ID

Program passes
associated COMPILE_ID

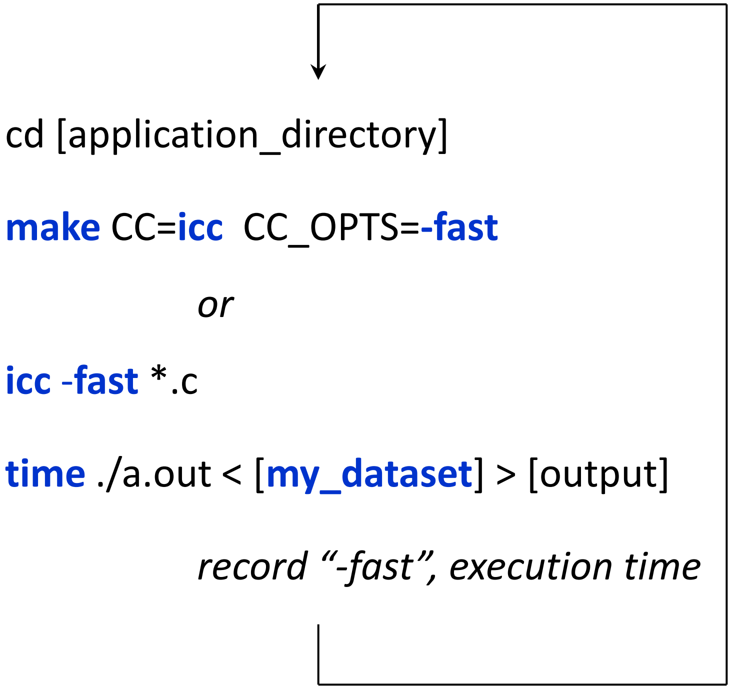
Program features
associated COMPILE_ID

Local or shared databases with optimization cases

# Problems with cTuning$_1$

- Difficult to extend (C, various hardwired components, need to change schema and types in MySQL)
- No convenient way of sharing modules, benchmarks, data sets, models (manual, csv files, emails, etc)
- Problems with repository scalability
- Complex, hardwired interfaces

# cTuning$_3$ aka Collective Mind framework basics



```
cd [application_directory]

make CC=icc  CC_OPTS=-fast

               or

icc -fast *.c

time ./a.out < [my_dataset] > [output]

               record "-fast", execution time
```

# cTuning$_3$ aka Collective Mind framework basics

cd [application_directory]

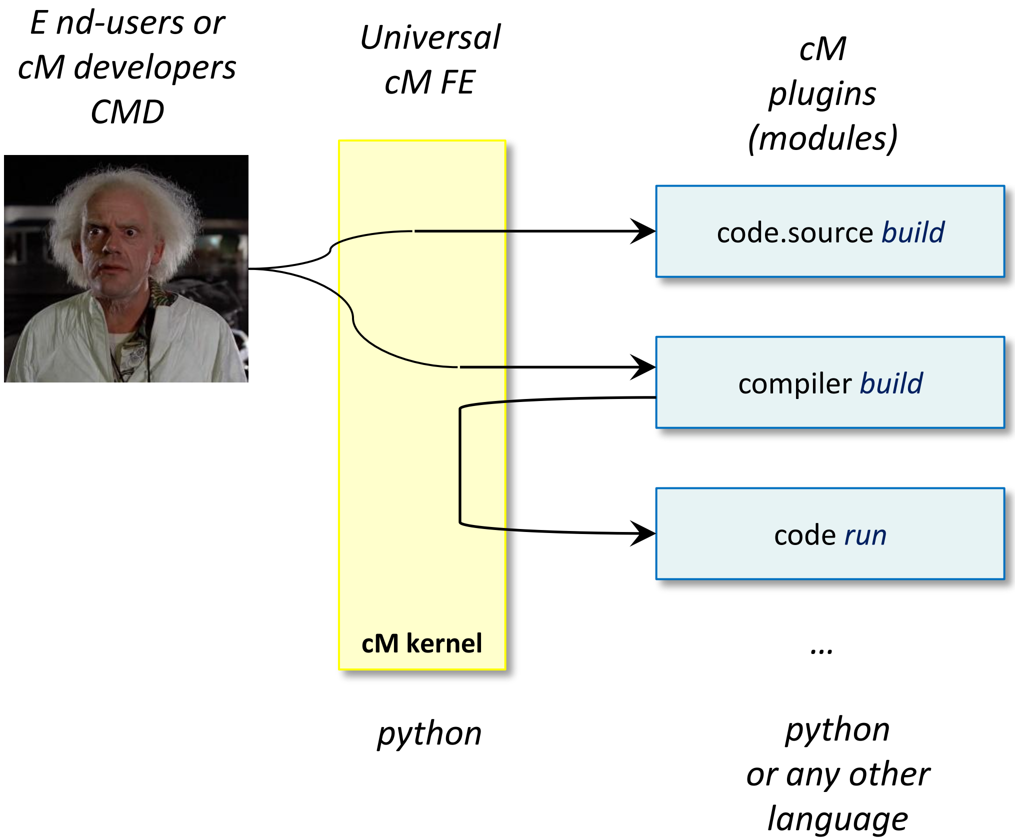
**make** CC=**icc** CC_OPTS=**-fast**

*or*

**icc** -**fast** *.c

**time** ./a.out < [**my_dataset**] > [output]

*record "-fast", execution time*



*E nd-users or cM developers CMD*

*Universal cM FE*

*cM plugins (modules)*

code.source *build*

compiler *build*

code *run*

…

**cM kernel**

*python*

*python or any other language*

# cTuning$_3$ aka Collective Mind framework basics

```
cd [application_directory]

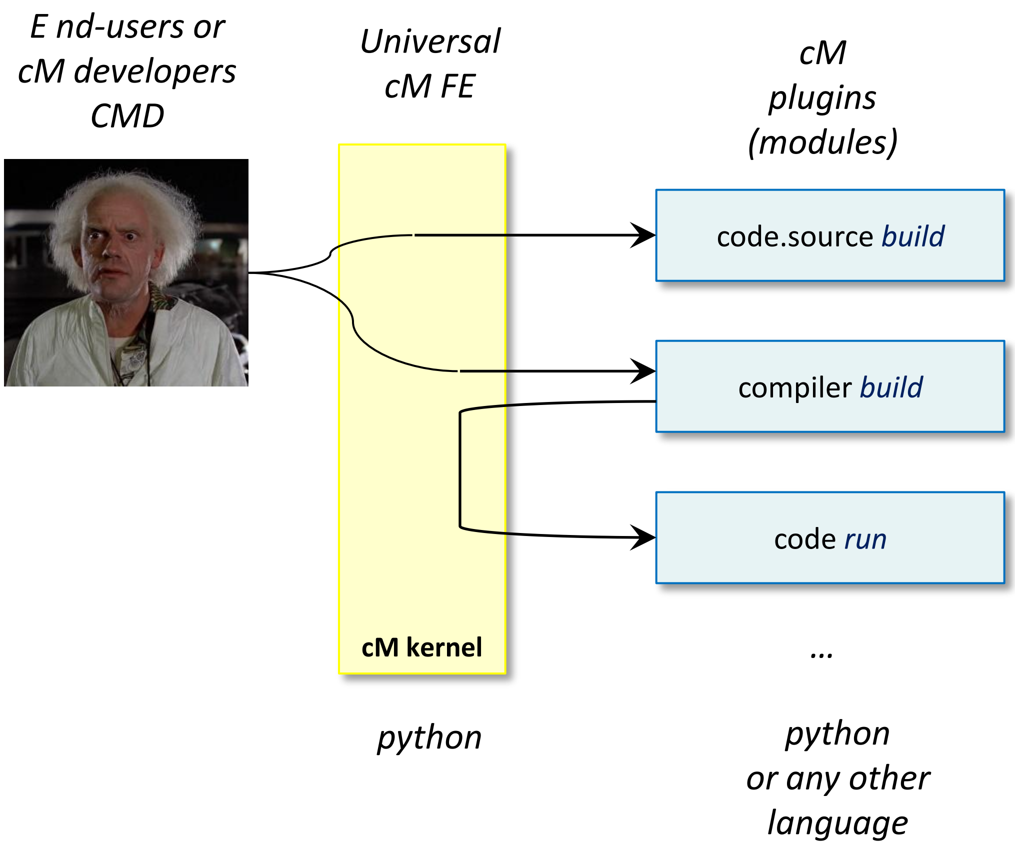
make CC=icc  CC_OPTS=-fast

            or

icc -fast *.c

time ./a.out < [my_dataset] > [output]

            record "-fast", execution time
```



E nd-users or cM developers CMD

Universal cM FE

cM plugins (modules)

cm [module name] [action] (param$_1$=value$_1$ param$_2$=value$_2$ … -- *unparsed command line*)

```
cm code.source build ct_compiler=icc13 ct_optimizations=-fast
cm compiler build -- icc -fast *.c
cm code run os=android binary=./a.out dataset=image-crazy-scientist.pgm
```

*Should be able to run on any OS (Windows, Linux, Android, MacOS, etc)!*

# cTuning$_3$ aka Collective Mind framework basics

Simple and minimalistic high-level cM interface - **one function (!)**

*should be easy to connect to any language if needed*

schema and type-free (only strings) -

easily extended when needed for research (agile methodology)!

(python dictionary) *output* = cm_kernel.access ( (python dictionary) *input* )

*Input:* {

cm_run_module_uoa - cM plugin name (or some UID)

cm_action - cM plugin action (function)

*parameters* - *(module and action dependent)*

}

*Output:* {

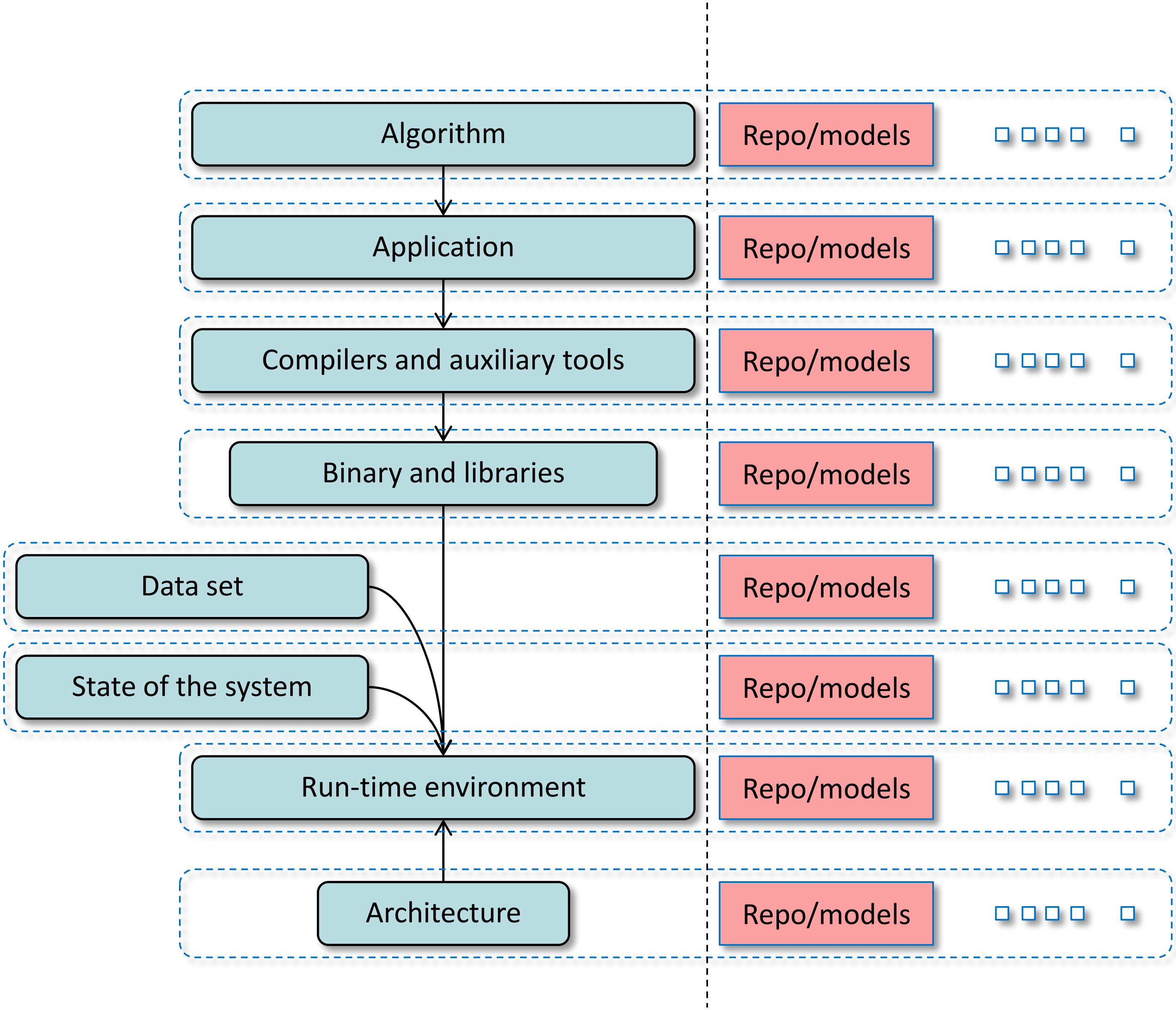
cm_return - if 0, success  
if >0, error  
if <0, warning

cm_error - if cm_return>0, error message

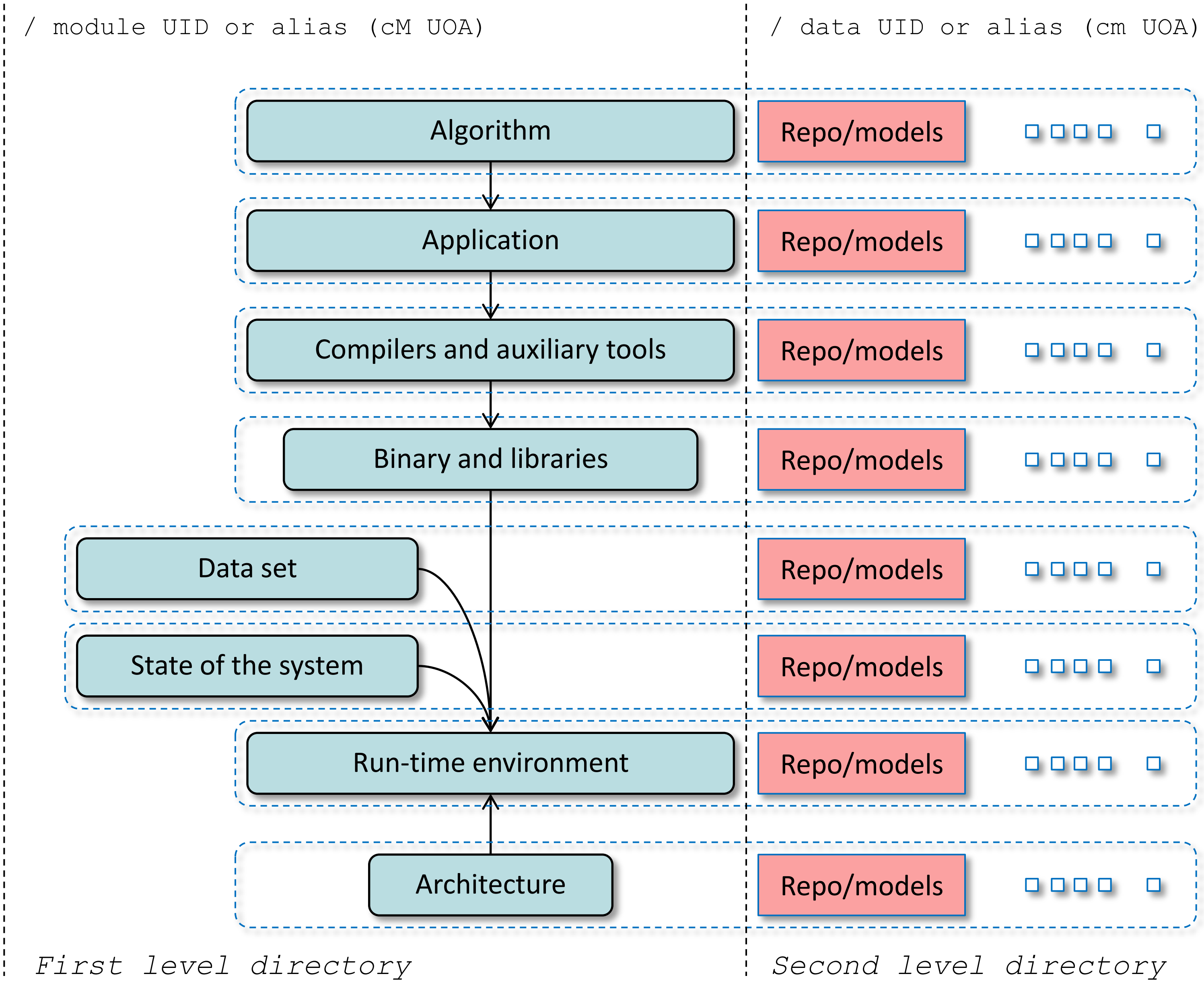
*parameters* - *(module and action dependent)*

}

# Collective Mind Repository basics



# Collective Mind Repository basics



*Very flexible and portable*

*Easy to access, edit and move data*

*Can be per application, experiment, architecture, etc*

*Can be easily shared (through web, SVN, GIT, FTP)*

# Schema-free extensible data meta-representation

cM uses **JSON** as internal data representation format:

*JSON or JavaScript Object Notation, is a text-based open standard designed for human-readable data interchange (from Wikipedia)*

- very intuitive to use and modify
- nearly native for python and php;   simple libraries for Java, C, C++, …
- easy to index with powerful indexing services (cM uses ElasticSearch)

cM records input and output of the module for reproducibility!

**Data is referenced by CID:**

`(Repository UID:) Module UID: Data UID`

# Schema-free extensible data representation

Example of JSON entry ***ctuning.compiler:icc-12.x-linux***

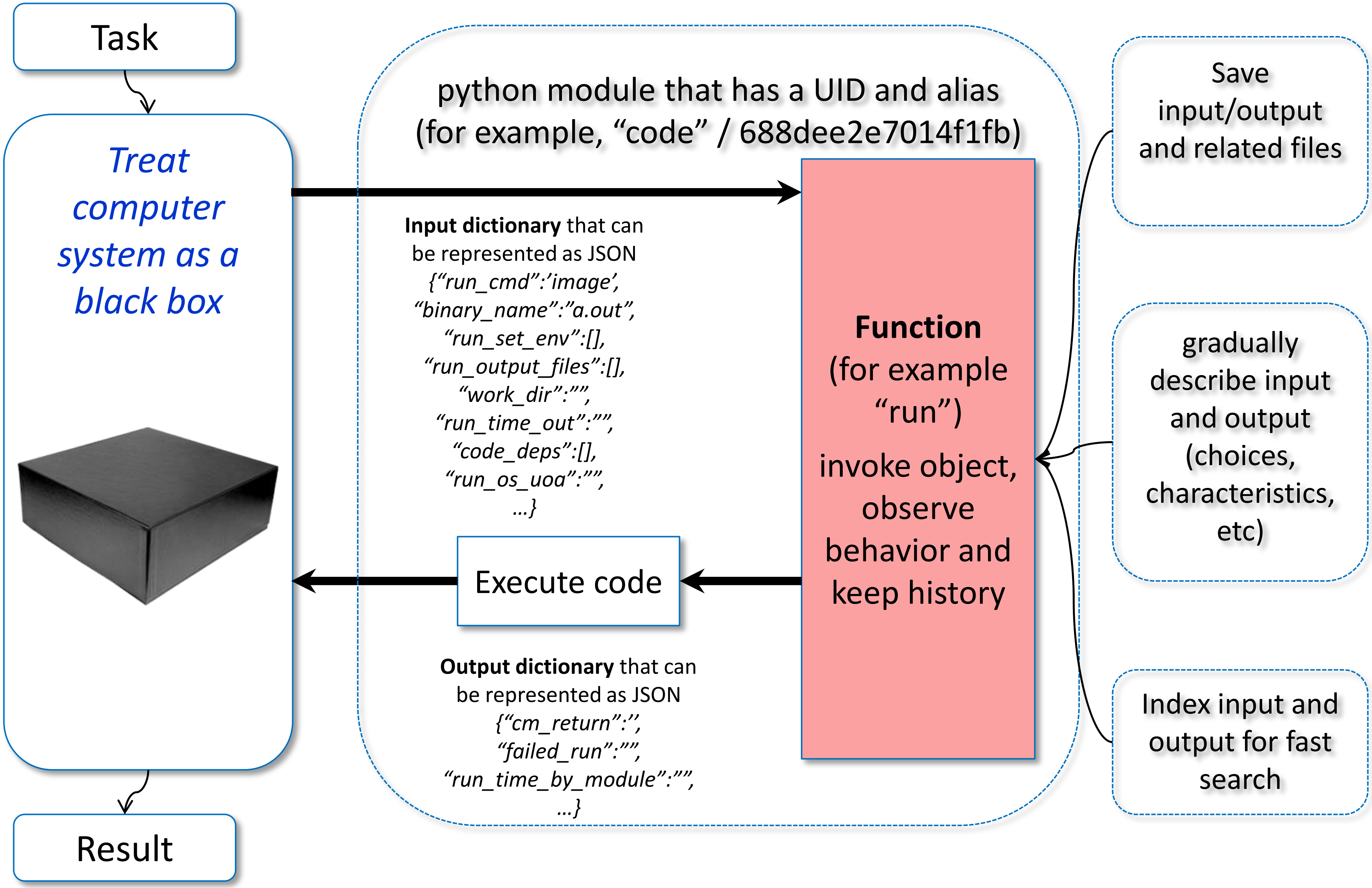
```
{
  "all_compiler_flags_desc": {

    "##base_flag": {
      "type": "text‶
      "desc_text": "compiler flag: -O3",
      "field_size": "7",

      "has_choice": "yes",
      "choice": [
        "-O0", "-O1", "-O2", "-Os", "-O3", "-fast"
      ],
      "default_value": "-O3",

      "explorable": "yes",
      "explore_level": "1",
      "explore_type": "fixed",
      "forbid_disable_at_random": "yes"
    },
    …
  }
…
}
```

# Universal modules/functions



Task

*Treat computer system as a black box*

Result

python module that has a UID and alias
(for example, "code" / 688dee2e7014f1fb)

**Input dictionary** that can be represented as JSON

*{"run_cmd":'image',*
*"binary_name":"a.out",*
*"run_set_env":[],*
*"run_output_files":[],*
*"work_dir":"",*
*"run_time_out":"",*
*"code_deps":[],*
*"run_os_uoa":"",*
*…}*

**Function**
(for example "run")

invoke object, observe behavior and keep history

Execute code

**Output dictionary** that can be represented as JSON

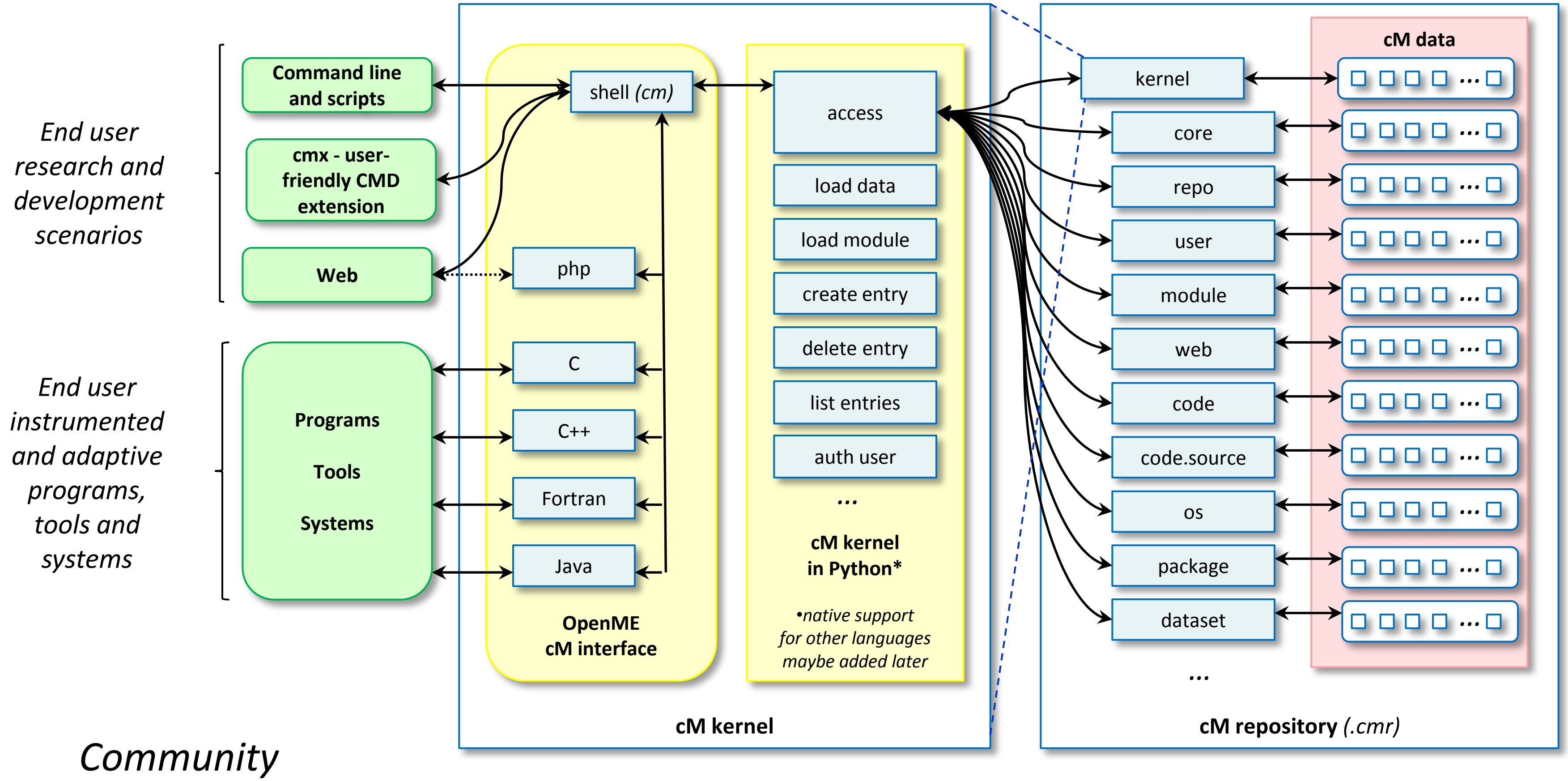
*{"cm_return":'',*
*"failed_run":"",*
*"run_time_by_module":"",*
*…}*

Save input/output and related files

gradually describe input and output (choices, characteristics, etc)

Index input and output for fast search

# Collective Mind overall structure


End user research and development scenarios

Command line and scripts

cmx - user-friendly CMD extension

Web

End user instrumented and adaptive programs, tools and systems

Programs

Tools

Systems

shell *(cm)*

php

C

C++

Fortran

Java

OpenME cM interface

access

load data

load module

create entry

delete entry

list entries

auth user

…

cM kernel in Python*

*•native support for other languages maybe added later*

cM kernel

cM data

kernel

core

repo

user

module

web

code

code.source

os

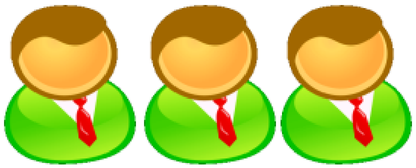
package

dataset

…

cM repository *(.cmr)*

*Community or workgroup*

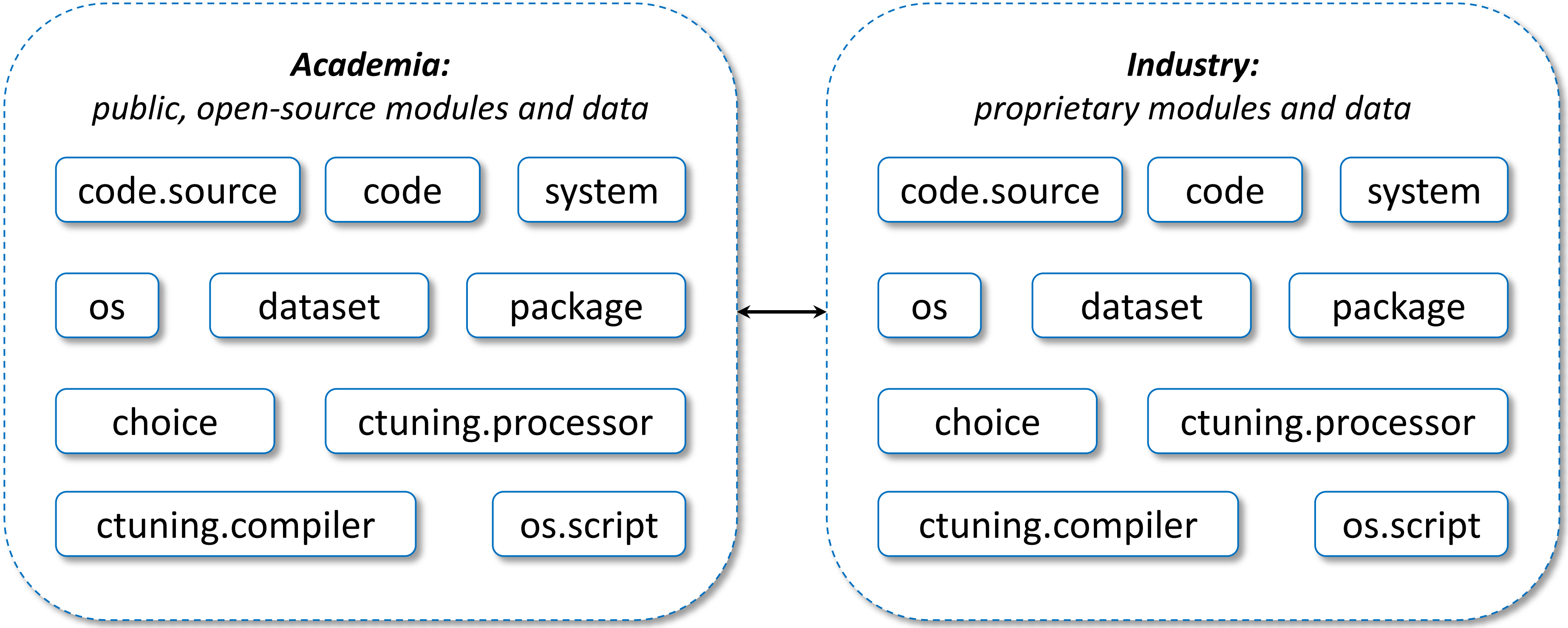


- Gradually add more modules, interfaces and data depending on user/project/company needs
- Gradually add more parameters
- Gradually expose choices, properties, characteristics

# Collaborative, reproducible experiments: research LEGO

- Continuously adding “basic blocks” (modules)
- Adding tools, applications, datasets
- Gradually stabilize interfaces

Users can start connecting modules and data together to prepare experimental pipelines with various observation, characterization, auto-tuning and predictive scenarios!



***Academia:***

*public, open-source modules and data*

code.source
code
system
os
dataset
package
choice
ctuning.processor
ctuning.compiler
os.script

***Industry:***

*proprietary modules and data*

code.source
code
system
os
dataset
package
choice
ctuning.processor
ctuning.compiler
os.script

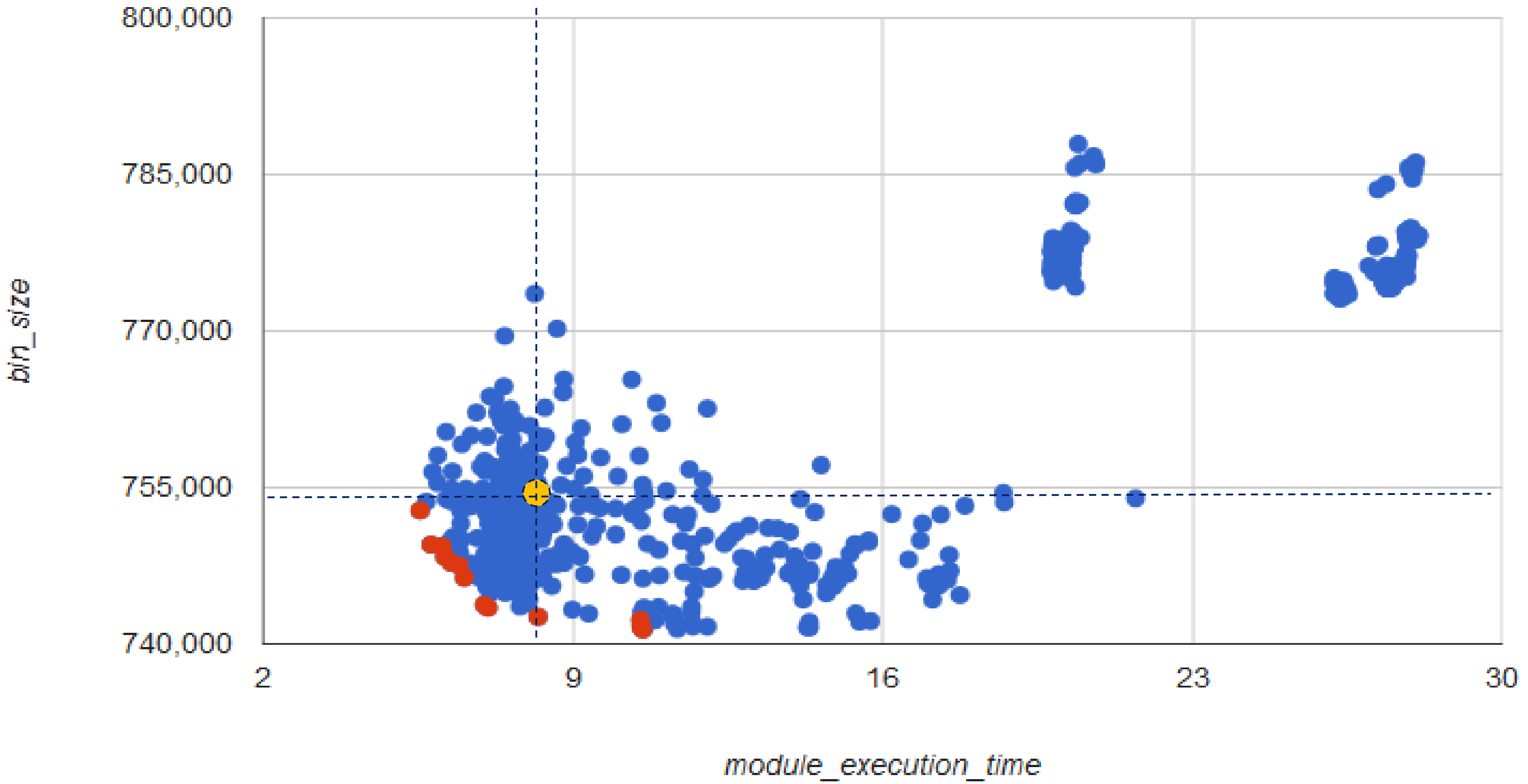
# Experimental pipelines for auto-tuning and modeling

- **Init pipeline**
- Detected system information
- Initialize parameters
- Prepare dataset
- **Clean program**
- **Prepare compiler flags**
- Use compiler profiling
- Use cTuning CC/MILEPOST GCC for fine-grain program analysis and tuning
- Use universal Alchemist plugin (with any OpenME-compatible compiler or tool)
- Use Alchemist plugin (currently for GCC)
- **Build program**
- Get objdump and md5sum (if supported)
- Use OpenME for fine-grain program analysis and online tuning (build & run)
- Use 'Intel VTune Amplifier' to collect hardware counters
- Use 'perf' to collect hardware counters
- Set frequency (in Unix, if supported)
- Get system state before execution
- **Run program**
- Check output for correctness (use dataset UID to save different outputs)
- Finish OpenME
- Misc info
- **Observed characteristics**
- Observed statistical characteristics
- **Finalize pipeline**

# Currently prepared experiments

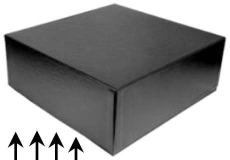
- Polybench - numerical kernels with exposed parameters of all matrices in cM
  - CPU: 28 prepared benchmarks
  - CUDA: 15 prepared benchmarks
  - OpenCL: 15 prepared benchmarks
- cBench - 23 benchmarks with 20 and 1000 datasets per benchmark
- Codelets - 44 codelets from embedded domain (provided by CAPS Entreprise)
- SPEC 2000/2006
- Description of 32-bit and 64-bit OS: Windows, Linux, Android
- Description of major compilers: GCC 4.x, LLVM 3.x, Open64/Pathscale 5.x, ICC 12.x
- Support for collection of hardware counters: perf, Intel vTune
- Support for frequency modification
- Validated on laptops, mobiles, tables, GRID/cloud - can work even from the USB key

# Visualize and analyze optimization spaces



| | | | |
|---|---|---|---|
| Program: | *cBench: susan corners* | Processor: | *ARM v6, 830MHz* |
| Compiler: | *Sourcery GCC for ARM v4.6.1* | OS: | *Android OS v2.3.5* |
| System: | *Samsung Galaxy Y* | Data set: | *MiDataSet #1, image, 600x450x8b PGM, 263KB* |

# Gradually increase granularity and complexity

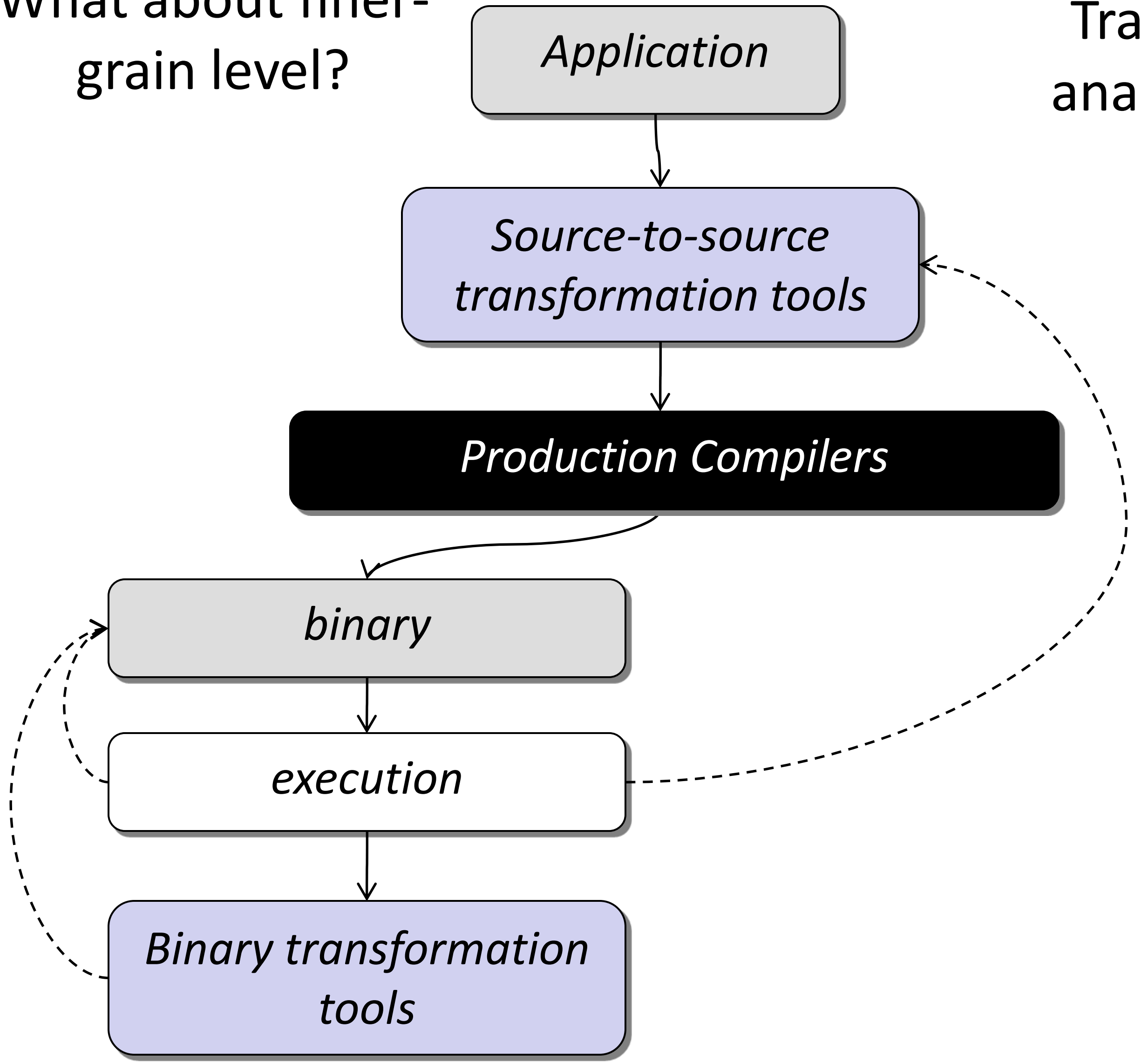


| | | | | Gradually expose some characteristics | Gradually expose some choices |
|---|---|---|---|---|---|
| | Algorithm selection | | | (time) productivity, variable-accuracy, complexity … | Language, MPI, OpenMP, TBB, MapReduce … |
| Compile Program | | | | time … | compiler flags; pragmas … |
| | Code analysis & Transformations | | | time;<br>memory usage;<br>code size … | transformation ordering;<br>polyhedral transformations;<br>transformation parameters;<br>instruction ordering … |
| | | Process | | | |
| | | Thread | | | |
| | | Function | | | |
| | | Codelet | | | |
| | | Loop | | | |
| | | | Instruction | | |
| Run code | Run-time environment | | | time; power consumption … | pinning/scheduling … |
| | System | | | cost; size … | CPU/GPU; frequency; memory hierarchy … |
| | Data set | | | size; values; description … | precision … |
| | Run-time analysis | | | time; precision … | hardware counters; power meters … |
| | Run-time state | | | processor state; cache state … | helper threads; hardware counters … |
| Analyze profile | | | | time; size … | instrumentation; profiling … |

Coarse-grain vs. fine-grain effects: depends on user requirements and expected ROI

# Interactive compilers, tools and applications

What about finer-grain level?


Application
Source-to-source transformation tools
Production Compilers
binary
execution
Binary transformation tools

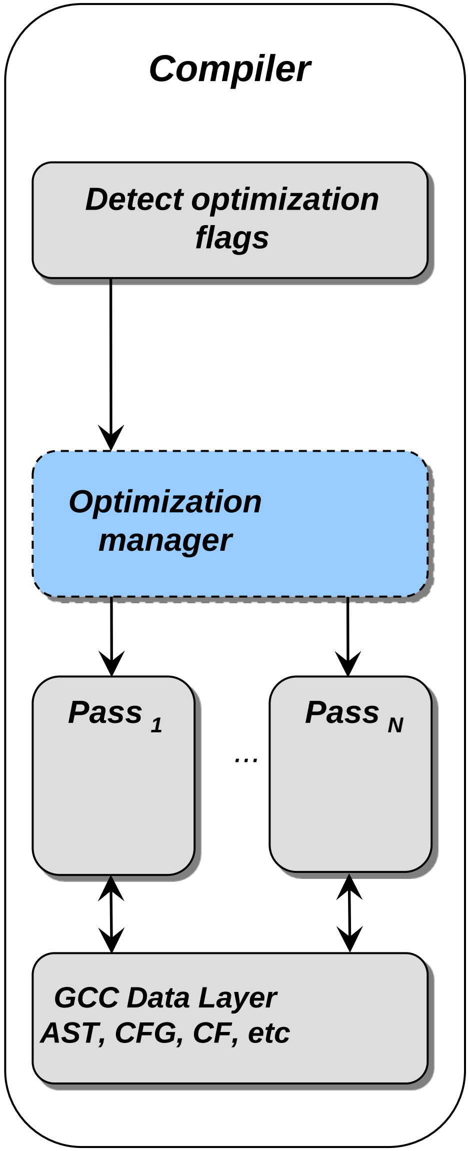
Traditional compilation, analysis and optimization

Often internal compiler decisions are not known or there is no precise control even through pragmas.

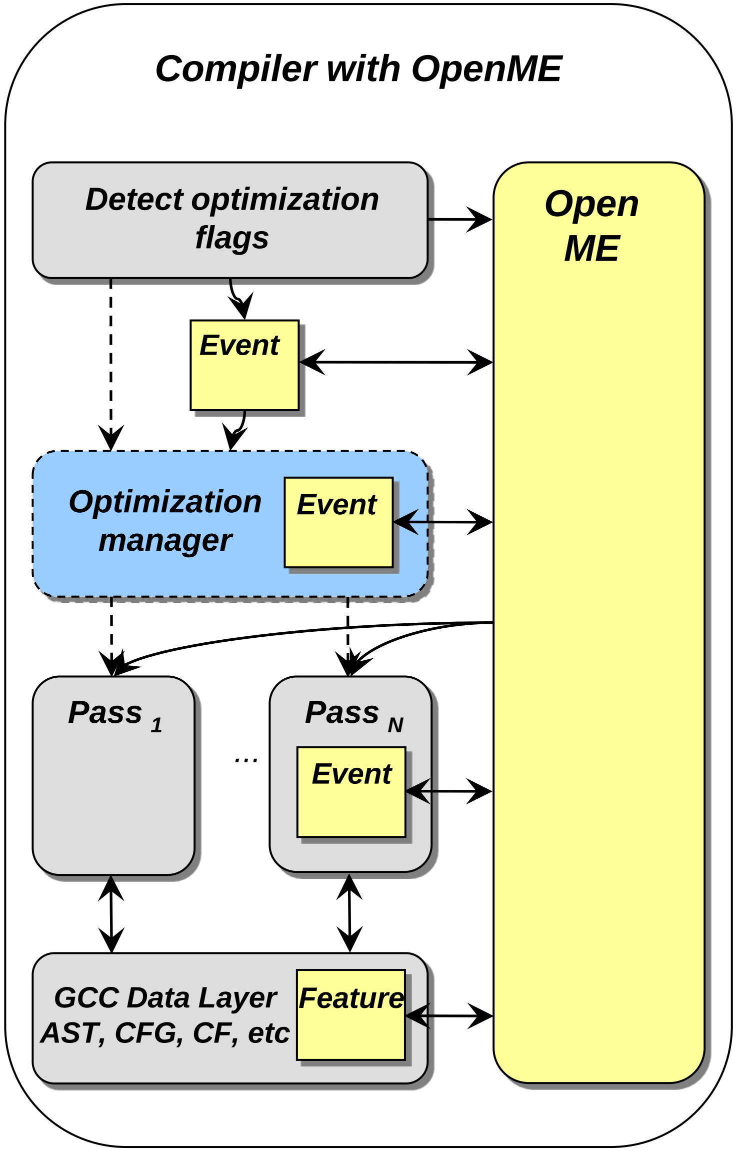
Interference with internal compiler optimizations complicates program analysis and characterization.

Current pragma based auto-tuning frameworks are very complex.

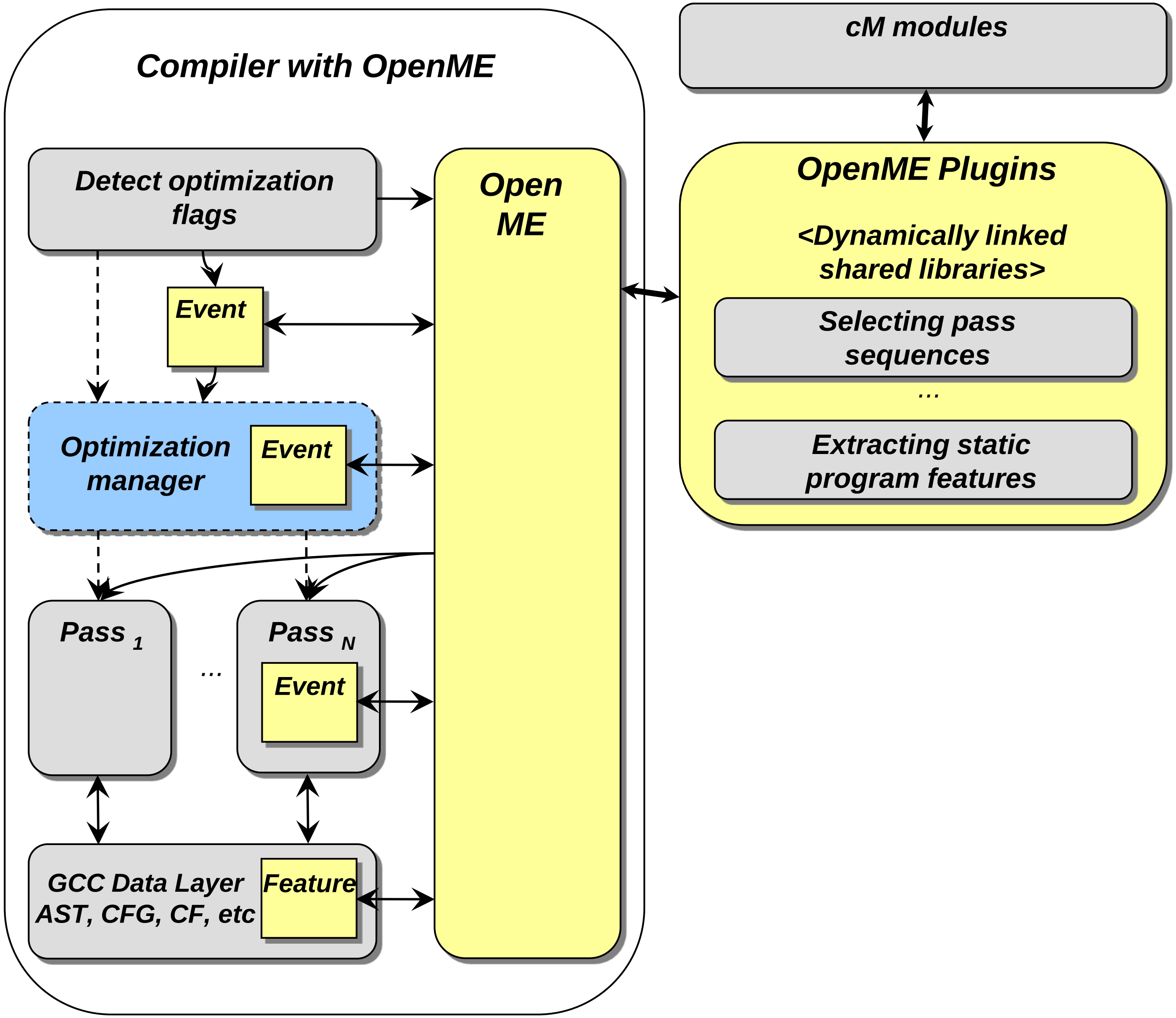
# OpenME - interactive plugin and event-based interface to "open up" applications and tools



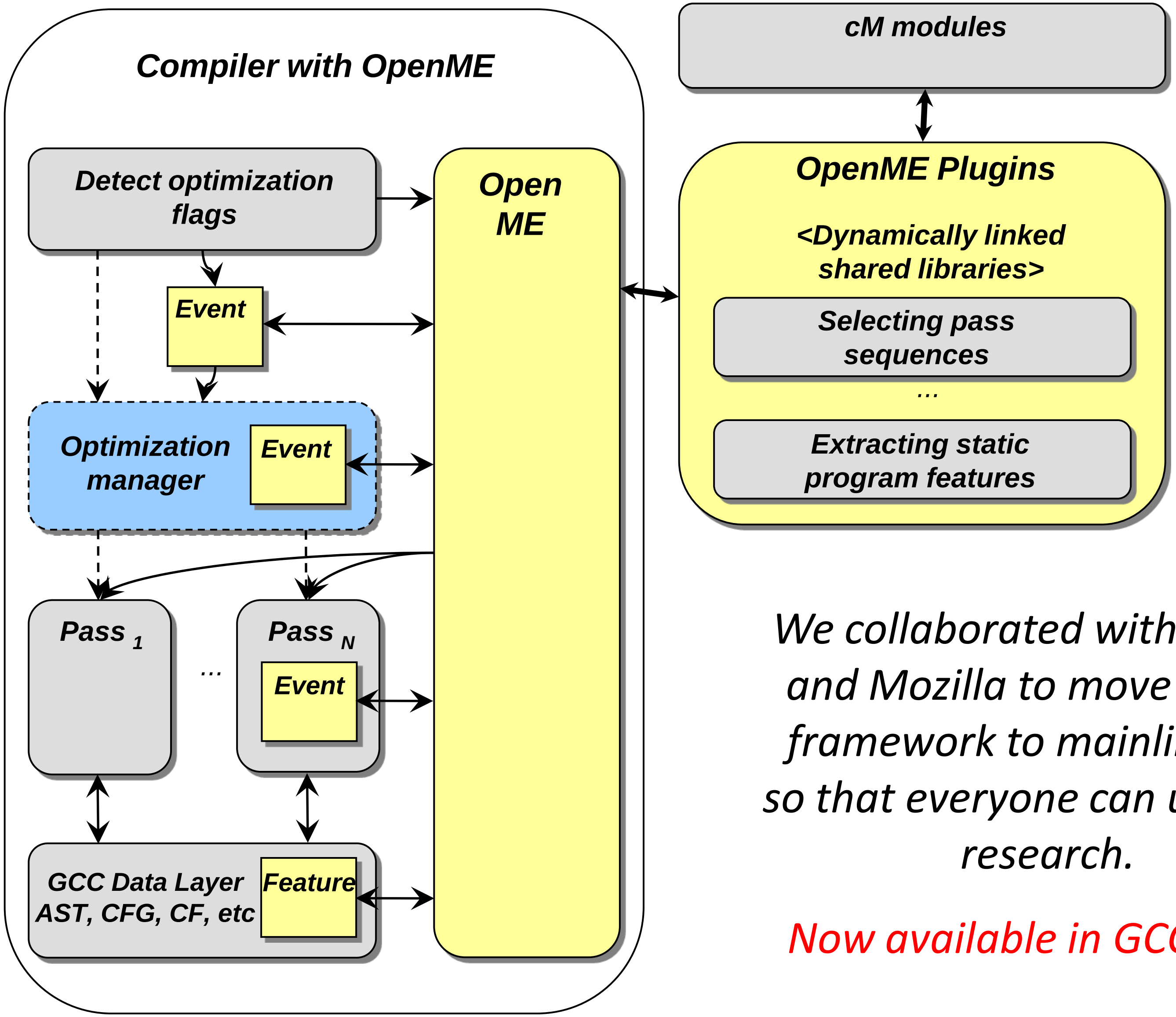
# OpenME - interactive plugin and event-based interface to "open up" applications and tools



# OpenME - interactive plugin and event-based interface to "open up" applications and tools



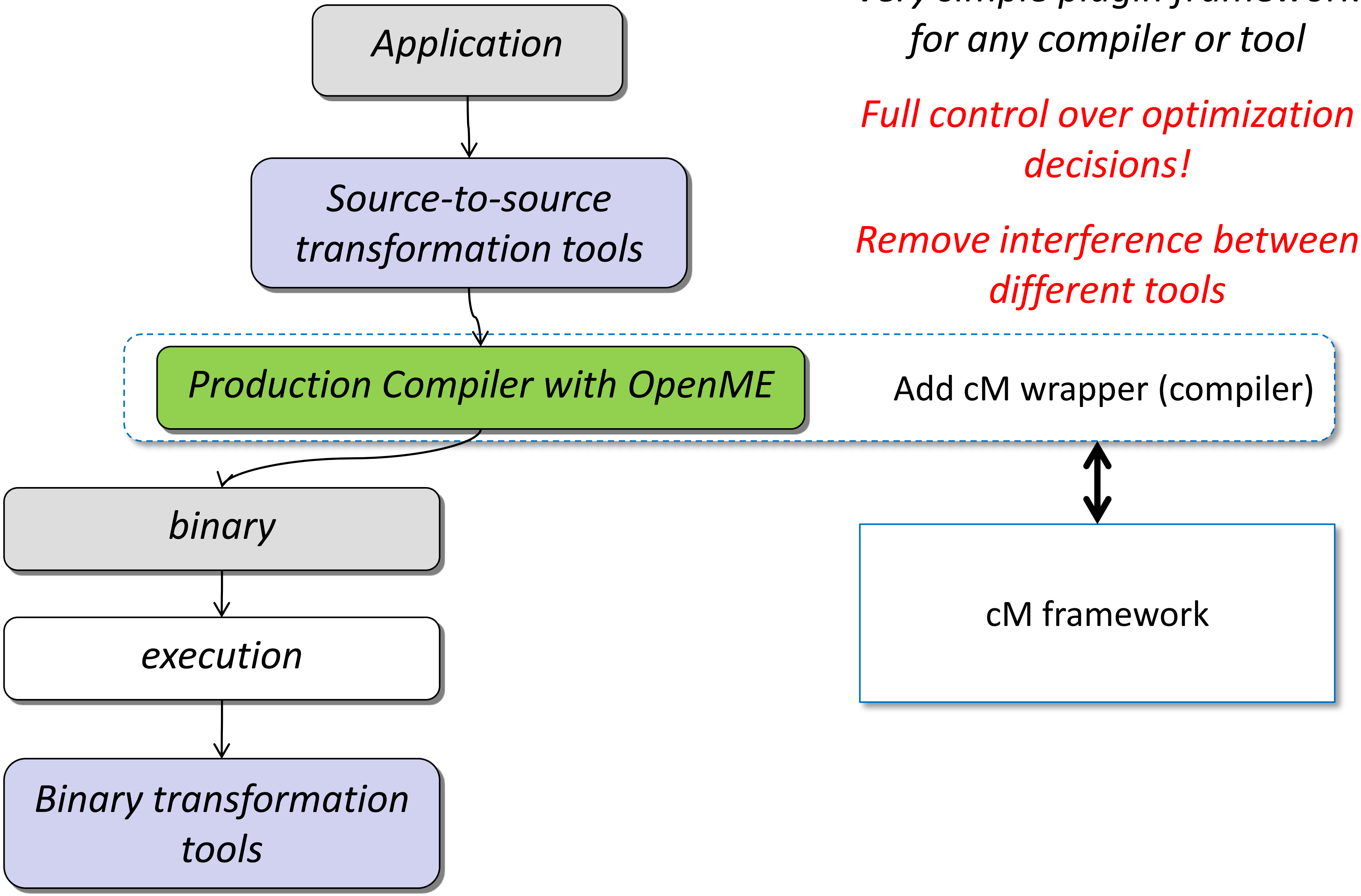
# OpenME - interactive plugin and event-based interface to "open up" applications and tools



*We collaborated with Google and Mozilla to move similar framework to mainline GCC so that everyone can use it for research.*

*Now available in GCC >=4.6*

# OpenME - interactive plugin and event-based interface to "open up" applications and tools


Application
Source-to-source transformation tools
Production Compiler with OpenME
Add cM wrapper (compiler)
binary
execution
Binary transformation tools
cM framework

*Very simple plugin framework for any compiler or tool*

*Full control over optimization decisions!*

*Remove interference between different tools*

# Example of OpenME for LLVM 3.2

**OpenME: 3 functions only!**

- *openme_init(…)* ***- initialize/load plugin***
- *openme_callback(char* event_name, void* params)* ***- call event***
- *openme_finish(…)* ***- finalize (if needed)***

**tools/clang/tools/driver/cc1_main.cpp**

```
#include "openme.h“
…
int cc1_main(const char **ArgBegin, const char **ArgEnd,
                    const char *Argv0, void *MainAddr) {

   openme_init("UNI_ALCHEMIST_USE", "UNI_ALCHEMIST_PLUGINS", NULL, 0);
   …
  // Execute the frontend actions.
  Success = ExecuteCompilerInvocation(Clang.get());
  openme_callback("ALC_FINISH", NULL);
   …
}
```

# Example of OpenME for LLVM 3.2

**lib/Transforms/Scalar/LoopUnrollPass.cpp**

```
#include <cJSON.h>
#include "openme.h“
…
bool LoopUnroll::runOnLoop(Loop *L, LPPassManager &LPM) {

  struct alc_unroll   {
    const char *func_name;
    const char *loop_name;
    cJSON *json;
    int factor;
   } alc_unroll;
…
alc_unroll.func_name=(Header->getParent()->getName()).data();
alc_unroll.loop_name=(Header->getName()).data();
openme_callback("ALC_TRANSFORM_UNROLL_INIT", &alc_unroll);
…
 // Unroll the loop.
alc_unroll.factor=Count;
openme_callback("ALC_TRANSFORM_UNROLL", &alc_unroll);
Count=alc_unroll.factor;

if (!UnrollLoop(L, Count, TripCount, UnrollRuntime, TripMultiple, LI, &LPM))
   return false;
…
}
```

# Example of OpenME for LLVM 3.2

## Alchemist plugin (.so/dll object) - in development
## for online/interactive analysis, tuning and adaptation

```
#include <cJSON.h>
#include <openme.h>

int openme_plugin_init(struct openme_info *ome_info) {
  …
   openme_register_callback(ome_info, "ALC_TRANSFORM_UNROLL_INIT", alc_transform_unroll_init);
  openme_register_callback(ome_info, "ALC_TRANSFORM_UNROLL", alc_transform_unroll);
  openme_register_callback(ome_info, "ALC_TRANSFORM_UNROLL_FEATURES", alc_transform_unroll_features);
  openme_register_callback(ome_info, "ALC_FINISH", alc_finish);
  …
}

extern void alc_transform_unroll_init(struct alc_unroll *alc_unroll){
   …
}

extern void alc_transform_unroll(struct alc_unroll *alc_unroll) {
  …
}
…
```

# Example of OpenME for OpenCL/CUDA C application

- 2mm.c / 2mm.cu

```
…
#ifdef OPENME
#include <openme.h>
#endif
…

int main(void) {
…
#ifdef OPENME
  openme_init(NULL,NULL,NULL,0);
  openme_callback("PROGRAM_START", NULL);
#endif
…
#ifdef OPENME
openme_callback("ACC_KERNEL_START", NULL);
#endif

cl_launch_kernel();
  or
mm2Cuda(A, B, C, D, E, E_outputFromGpu);

#ifdef OPENME
openme_callback("ACC_KERNEL_END", NULL);
#endif
…
```

```
…
#ifdef OPENME
 openme_callback("KERNEL_START", NULL);
#endif

mm2_cpu(A, B, C, D, E);

#ifdef OPENME
  openme_callback("KERNEL_END", NULL);
#endif

#ifdef OPENME
openme_callback("PROGRAM_END", NULL);
#endif
…
}
```

# Example of OpenME for Fortran application

- **matmul.F**

```
 PROGRAM MATMULPROG
…

 INTEGER*8 OBJ, OPENME_CREATE_OBJ_F
CALL OPENME_INIT_F(""//CHAR(0), ""//CHAR(0), ""//CHAR(0), 0)
CALL OPENME_CALLBACK_F("PROGRAM_START"//CHAR(0))

…
 CALL OPENME_CALLBACK_F("KERNEL_START"//CHAR(0));
DO I=1, I_REPEAT
  CALL MATMUL
END DO
CALL OPENME_CALLBACK_F("KERNEL_END"//CHAR(0));

…
 CALL OPENME_CALLBACK_F("PROGRAM_END"//CHAR(0))
END
```

# Next steps

1) Prepare pre-release around May/June 2013 (BSD-style license) - **ASK for preview!**
2) Reproduce my past published research within new framework:
   - Add “classical” classification and predictive models
   - Add various exploration strategies (random, focused)
   - Add run-time adaptation scenarios (CUDA/OpenCL scheduling, pinning, etc)
   - Add co-design scenarios
3) Use framework for analysis and auto-tuning of industrial applications
4) Help to customize framework for industrial usages (consulting)
5) Applying for new funding (academic and industrial)
6) Continue virtual collaborative cTuning Lab to build community:
   - Public repository to share applications, datasets, models at cTuning.org:
   - New publication model for reproducible research
   - Community R&D discussion

     ***http://groups.google.com/group/collective-mind***
   - Collect data from Android mobiles

# Acknowledgements

- PhD students and postdocs (my Intel Exascale team)

  *Abdul Wahid Memon, Pablo Oliveira, Yuriy Kashnikov*

- Colleague from NCAR, USA

  *Davide Del Vento and his colleagues/interns*

- Colleagues from IBM, CAPS, ARC (Synopsys), Intel, Google, ARM, ST
- Colleagues from Intel (USA)

  *David Kuck and David Wong*

- cTuning community:

  Collective TUNING

- EU FP6, FP7 program and HiPEAC network of excellence

  http://www.hipeac.net

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