# oclude and OCLMan

## tools to profile and predict the dynamic behavior of standalone OpenCL kernels based on compiling and machine learning techniques

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# Outline I

1 Introduction
- It is a heterogeneous world
- Utilizing diversity
- Related work

2 oclude
- The need for a profiler
- A glimpse of OpenCL
- An overview of oclude

# Outline II

3 OCLBoi
- Towards the instcounts model
- The design of OCLBoi
- OCLBoi and the Rodinia Suite

4 OCLMan
- A boy needs a father
- The design of OCLMan
- Evaluating OCLMan

5 Future work

# What is heterogeneous computing?

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## Towards a definition (1/2)

*"Todays computing environments are becoming more multifaceted, exploiting the capabilities of a range of* **multi-core microprocessors**, *central processing units (***CPUs***), digital signal processors, reconfigurable hardware (***FPGAs***), and graphic processing units (***GPUs***)."*[1]

[1] Gaster, Benedict et al. *Heterogeneous Computing with OpenCL*. 1st ed. 2011.

# What is heterogeneous computing?

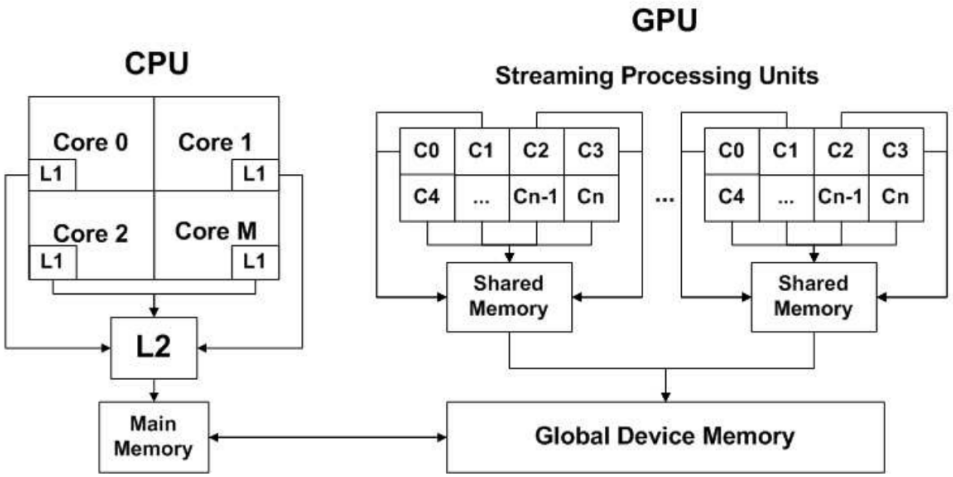


Figure: A simple heterogeneous system[1]

[1] Ravi, Vignesh et al. *Proceedings of the International Conference on Supercomputing*. "Compiler and runtime support for enabling generalized reduction computations on heterogeneous parallel configurations". 2010.

# What is heterogeneous computing?

## Towards a definition (2/2)

*"The definition of this term is quite straightforward:*
**executing programs on a computing platform with computing nodes of different characteristics**.

*What is tricky is whether this is a good thing or a bad thing."*[1]

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*"Heterogeneous computer systems [. . . ] add richness by allowing the programmer to select the best architecture to execute the task at hand or to choose the right task to make optimal use of a given architecture"*[2]

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Non-trivial tasks... unless we manage to predict the **execution time** of a *specific* application on a *specific* processing unit

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- We will be working with the OpenCL framework for heterogeneous computation...
- ... but we will **not be limited by it!**

# The dominant approach

*What to use and how to use it in order to predict execution time?*

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- **static** source code features (e.g. # of instructions, # of basic blocks etc.)[a]

[a] Wen, Yuan, Wang, Zheng, and O'Boyle, Michael. "Smart multi-task scheduling for OpenCL programs on CPU/GPU heterogeneous platforms". 2014.

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*What to use and how to use it in order to predict execution time?*

- **static** source code features (e.g. # of instructions, # of basic blocks etc.)[a]
- heavy **source code analysis** (e.g. loop bound analysis, path analysis etc.)[b]

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# The dominant approach

*What to use and how to use it in order to predict execution time?*

- However, building analytical models has been deemed obsolete[a], due to:
  1. the **complexity** of the process
  2. **over-simplistic assumptions** that are needed

[a] Huang, Ling et al. "Predicting Execution Time of Computer Programs Using Sparse Polynomial Regression". 2010.

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- **dynamic/runtime** program features (e.g. # of **executed** instructions)
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  - uncover the **runtime behavior** of the application

# An alternative approach

*How to extract dynamic features from an application?*

[3] Yang, L. T., Xiaosong Ma, and Mueller, F. "Cross-Platform Performance Prediction of Parallel Applications Using Partial Execution". 2005.

[4] Chun, Byung-Gon et al. "Mantis: Predicting System Performance through Program Analysis and Modeling". 2010.

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- **partial execution**[3]: *"very short testdrives of applications on multiple candidate platforms to quickly derive the execution time of much longer runs."*

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- **partial execution**[3]: *"very short testdrives of applications on multiple candidate platforms to quickly derive the execution time of much longer runs."*
- **instrumentation** and **feature evaluators**[4]: *"automatically extract small code snippets (feature evaluators) that compute feature values from the instrumented program."*

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$$\boldsymbol{gsize} \longmapsto \boldsymbol{instcounts} \longmapsto t_{exec}$$

# Decoupling input size and execution time

- $gsize \longmapsto instcounts$ : application-specific, hardware-agnostic
- $instcounts \longmapsto t_{exec}$ : application-agnostic, hardware-specific

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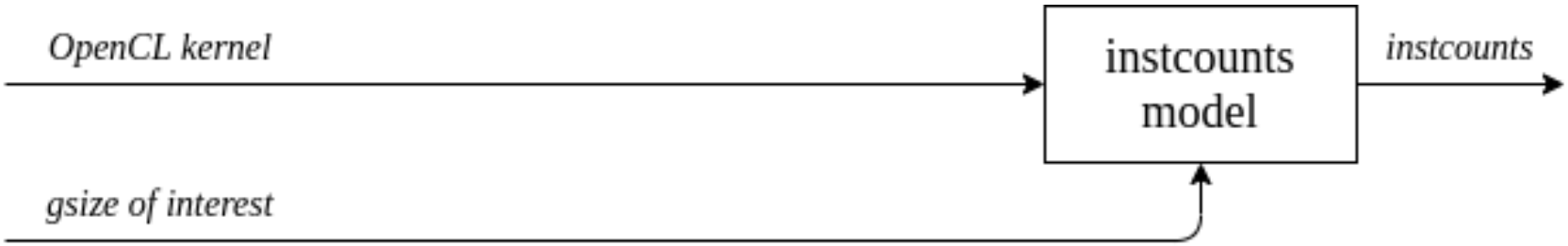

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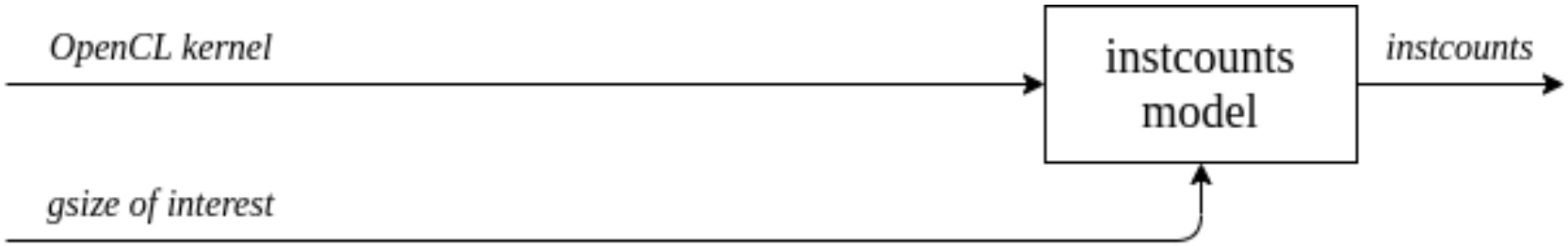


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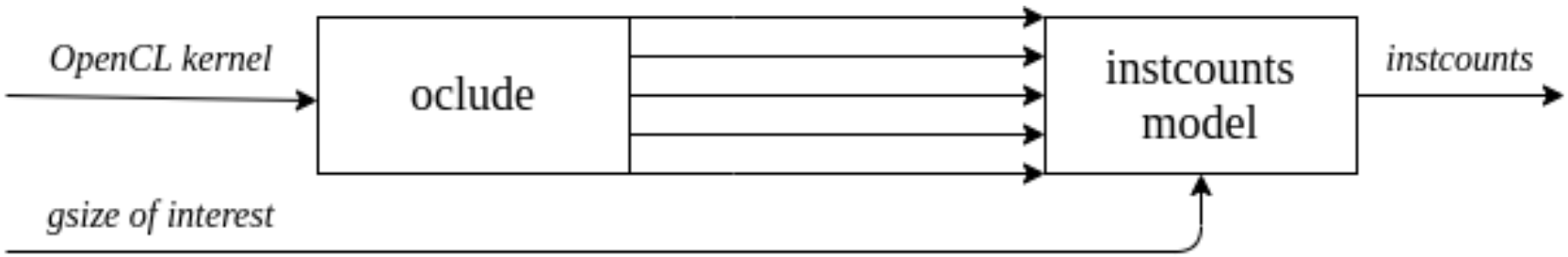


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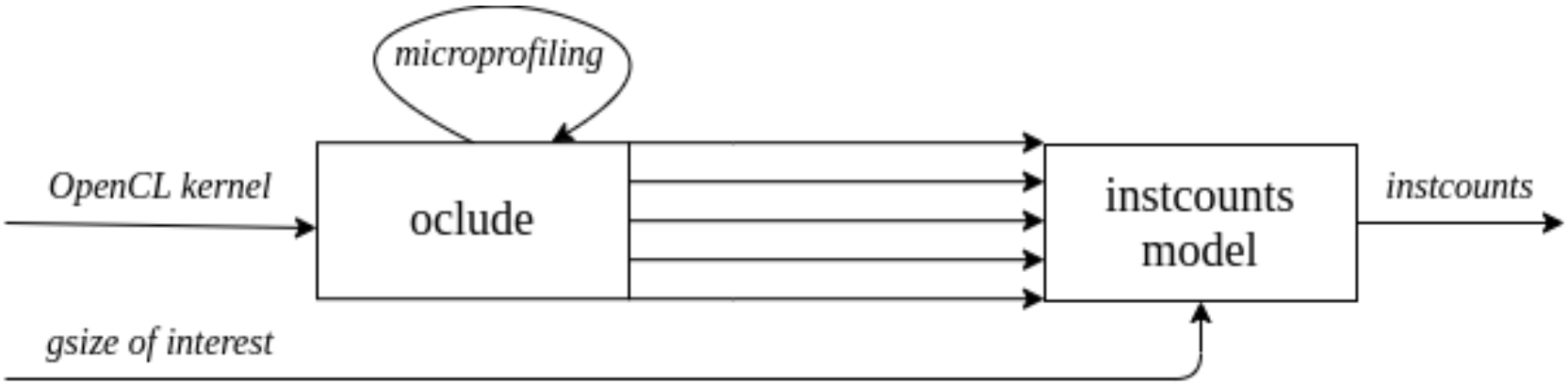


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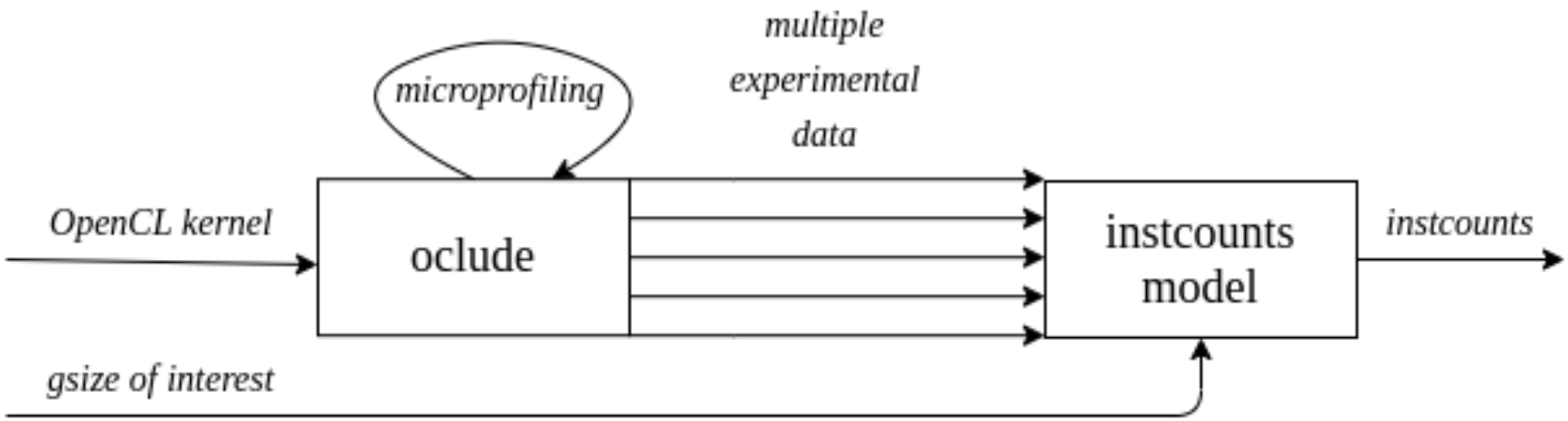


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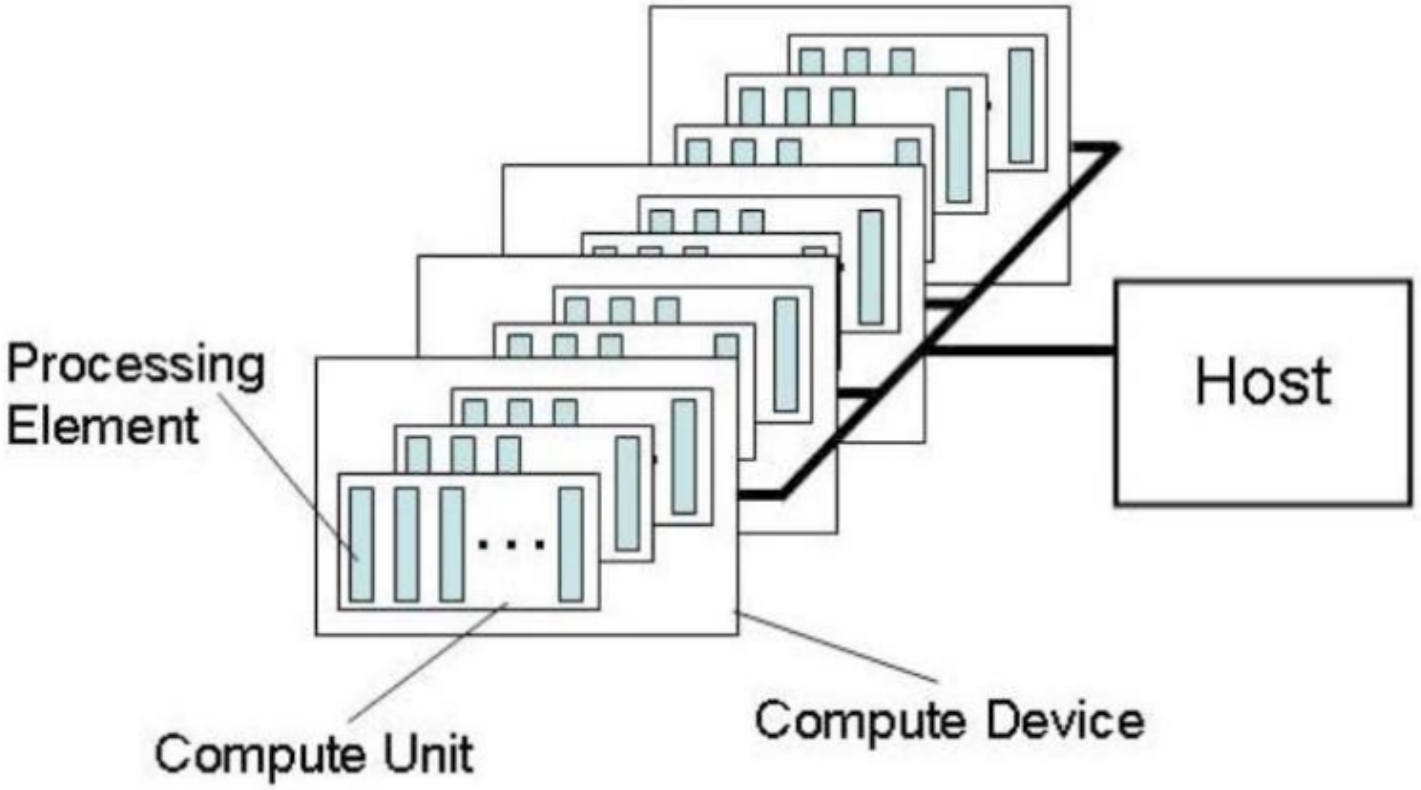
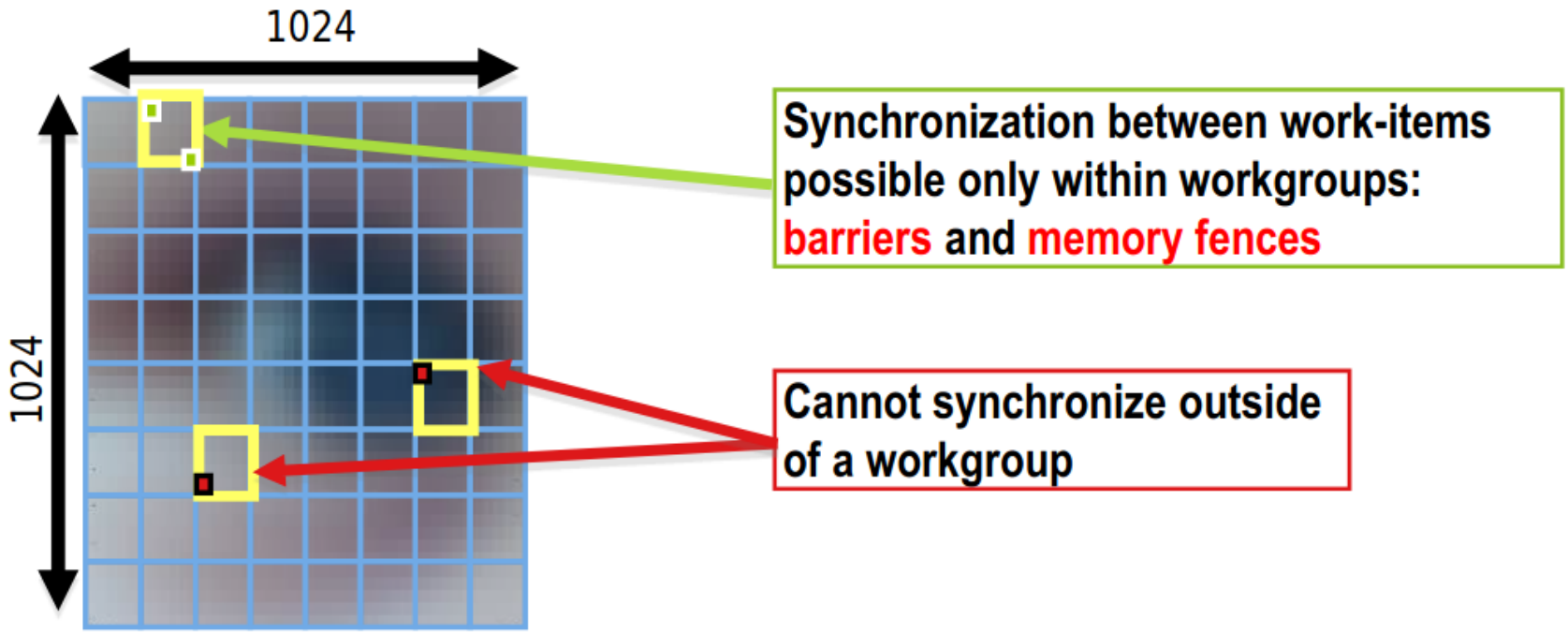
- it is **not** a specific implementation

# The OpenCL execution model

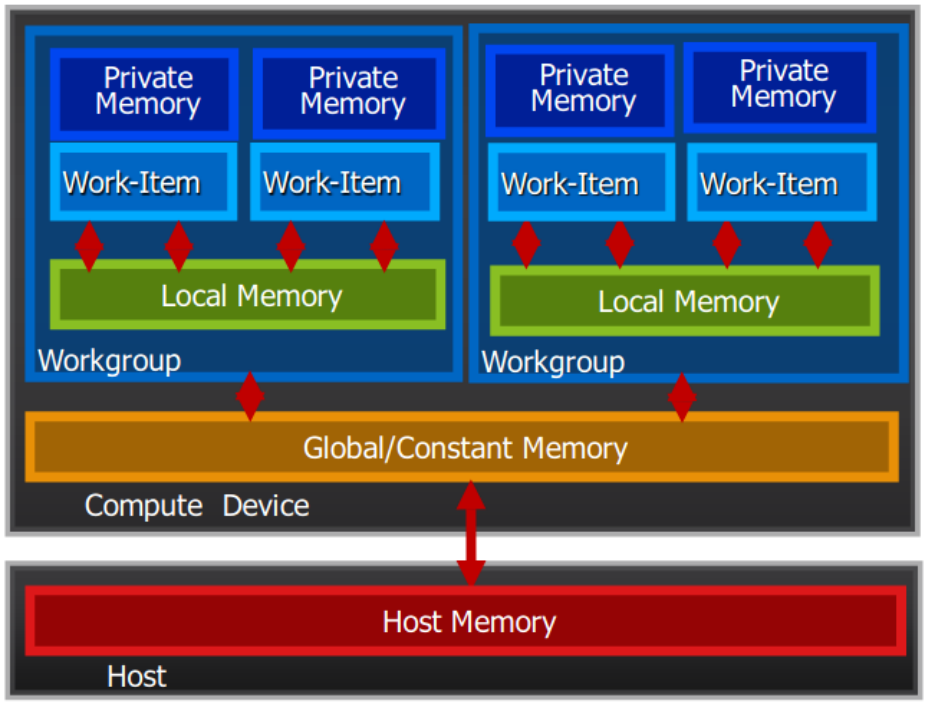


# The OpenCL task grid

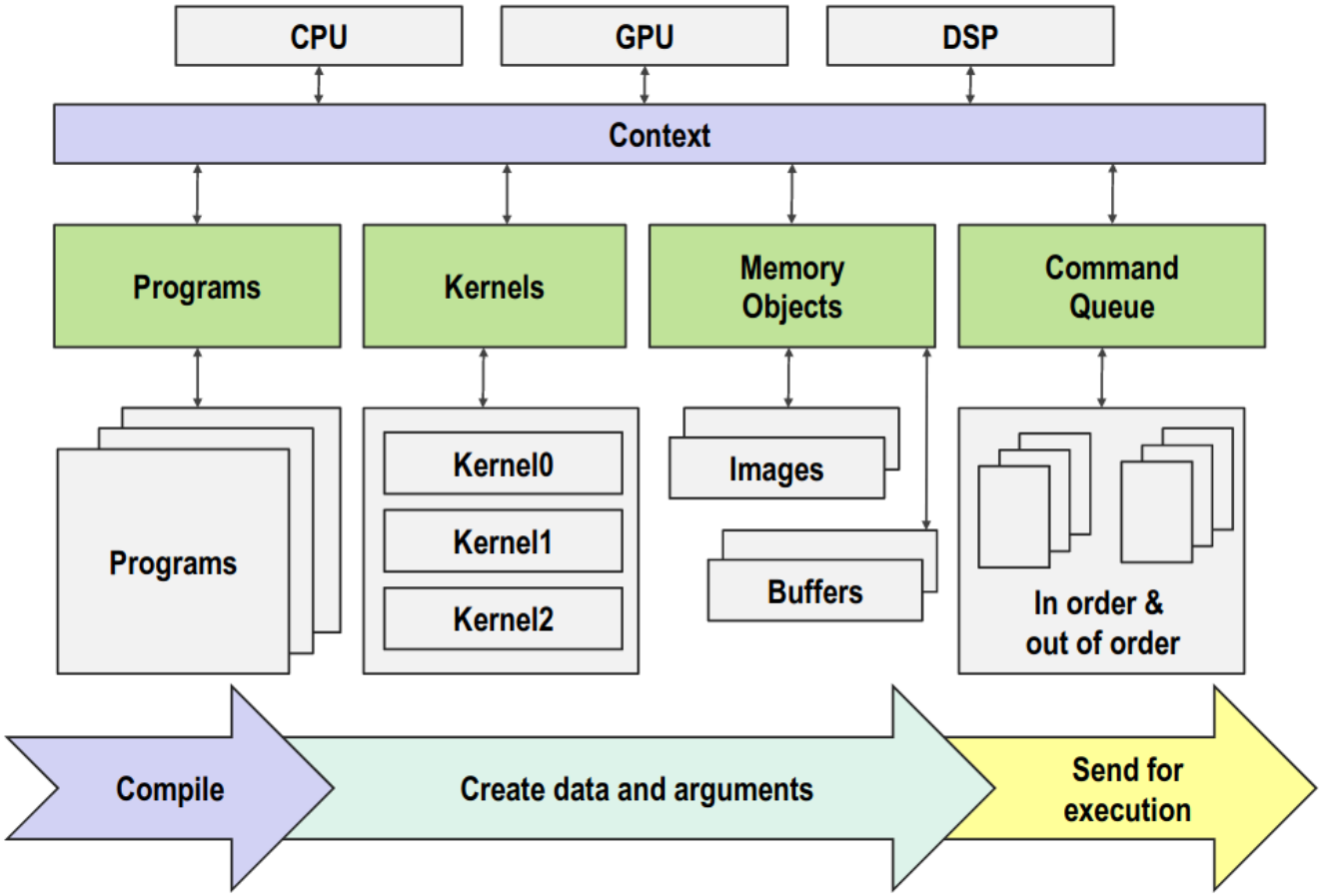


# The OpenCL memory model

- **Private Memory**
  - per *work-item*
- **Local Memory**
  - shared within a *workgroup*
- **Global/Constant Memory**
  - visible to all workgroups
- **Host Memory**
  - on the CPU



# A complete overview of the OpenCL workflow



# An overview of oclude

**What it is**

- An open-source standalone OpenCL kernel runner and profiler[5]
- The most technically challenging component of our work
- `Python 3`, `C++`
- Ways to use it:
  1. As a **command line utility** on Unix-like OSs
  2. As a **Python package**

[5] `https://github.com/zehanort/oclude`

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## What it does

- In our work, **dynamic features = executed LLVM instructions (instcounts)**

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[6] Klöckner, Andreas et al. *Parallel Computing*. "PyCUDA and PyOpenCL: A Scripting-Based Approach to GPU Run-Time Code Generation". 2012.

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  4. kernel execution through the **PyOpenCL API**[6]

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# An overview of oclude

## An example of usage

```
$ oclude -f com_dwt.cl -k c_CopySrcToComponents -g 1024 -it
... (info on standard error) ...
Instructions executed for kernel 'c_CopySrcToComponents':
           20480 - load private
           14336 - alloca
           14336 - store private
           12288 - add
           11264 - mul
            9216 - getelementptr
            9216 - sext
            4096 - call
            3072 - load global
            3072 - load local
            3072 - store local
            3072 - zext
            2048 - trunc
            1024 - ret
            1024 - br
            1024 - icmp
Time measurement info regarding the execution for kernel 'c_CopySrcToComponents' (in milliseconds):
hostcode - 7.42030143737793
  device - 5.3919999999999995
transfer - 2.0283014373779302
```

# An overview of oclude

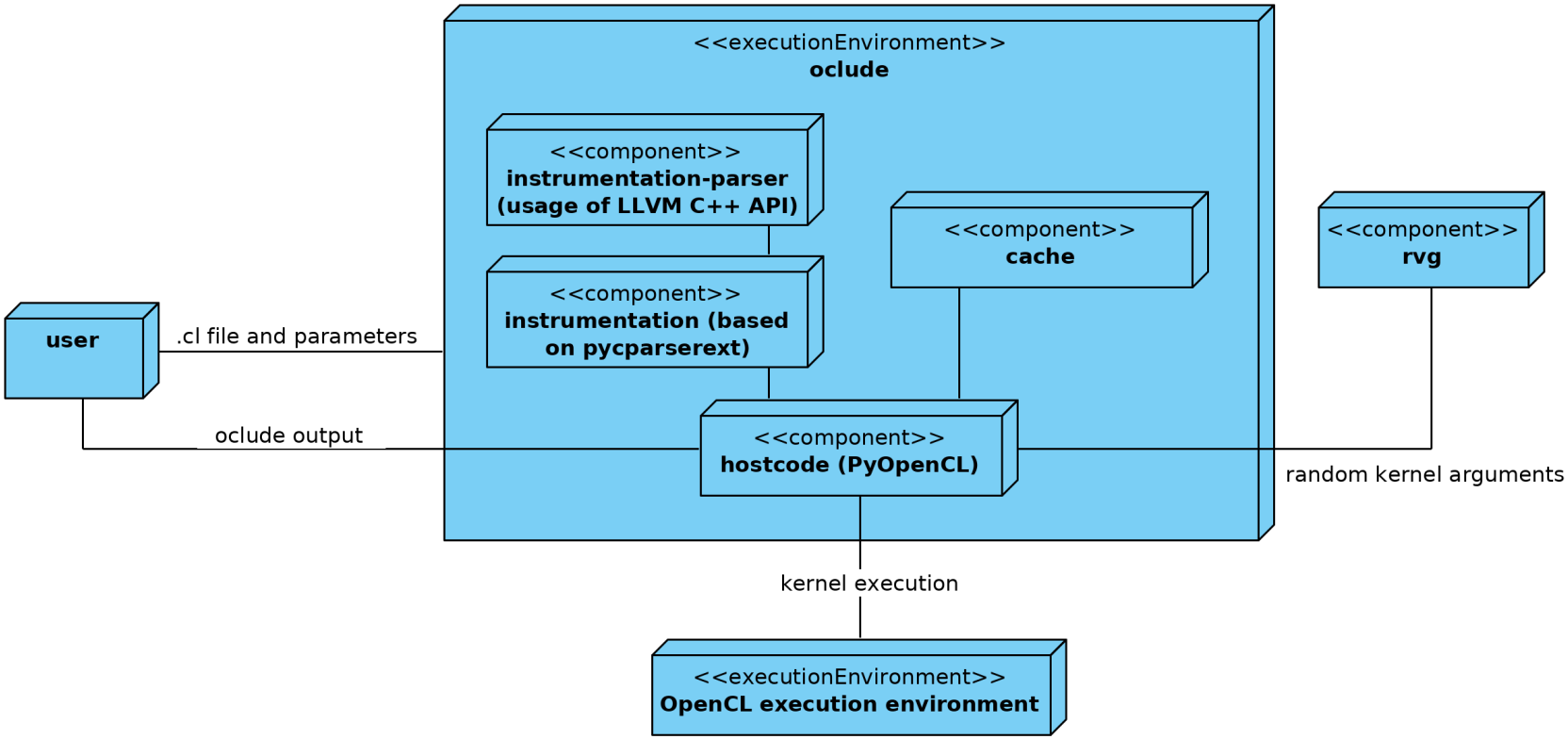



Figure: oclude UML component diagram

# Before and after instrumentation

```
__kernel void
vadd(__global int *a,
     __global int *b,
     __global int *c) {

int i = get_global_id(0);
c[i] = a[i] +  b[i];
}
```

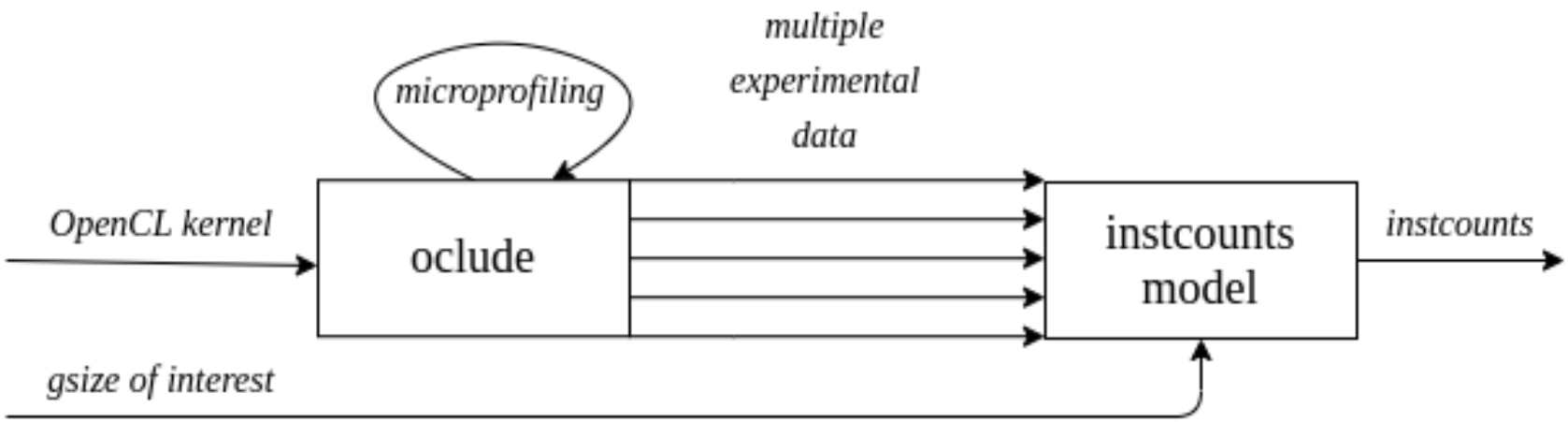
```
__kernel void
vadd(__global int *a,
     __global int *b,
     __global int *c,
     __local ulong *ocludeHiddenCounterLocal,
     __global ulong *ocludeHiddenCounterGlobal) {

  if (get_local_id(0) == 0)
    for (int i = 0; i < 73; i++)
    ocludeHiddenCounterLocal[i] = 0;
  barrier(CLK_GLOBAL_MEM_FENCE);

  /* alloca */
  atom_add(& ocludeHiddenCounterLocal[24], 6);
  /* store private */
  atom_add(& ocludeHiddenCounterLocal[30], 6);
  ...
  int i = get_global_id(0);
  c[i] = a[i] + b[i];

  barrier(CLK_GLOBAL_MEM_FENCE);
  if (get_local_id(0) == 0)
    for (int i = 0; i < 73; i++)
    atom_add(& ocludeHiddenCounterGlobal[i],
             ocludeHiddenCounterLocal[i]);
}
```

# A quick reminder



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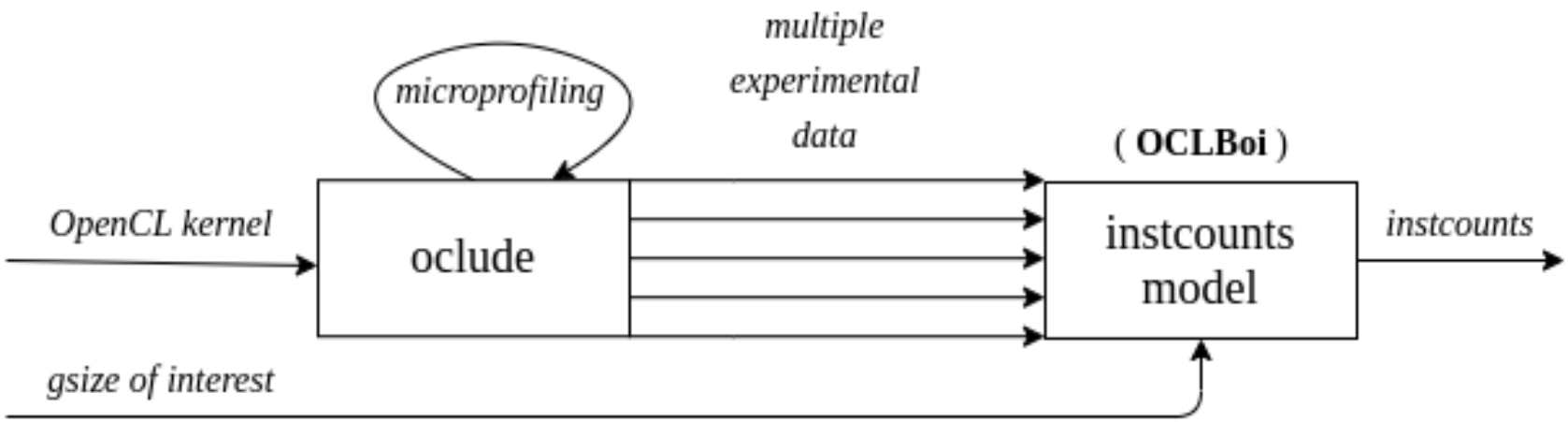

# Profiling kernels with oclude

The experimental process

- We worked with the OpenCL kernels of the **Rodinia Benchmark Suite**[7]

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The experimental process

- We worked with the OpenCL kernels of the **Rodinia Benchmark Suite**[7]
- We profiled each kernel for **a range of gsizes**
- We took **100 samples for each gsize value**

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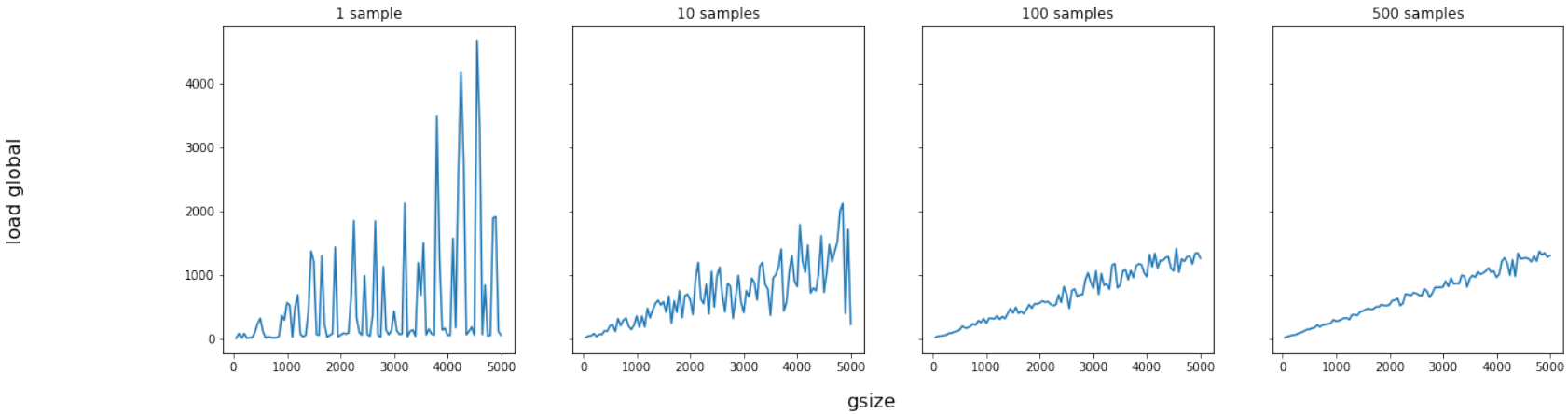
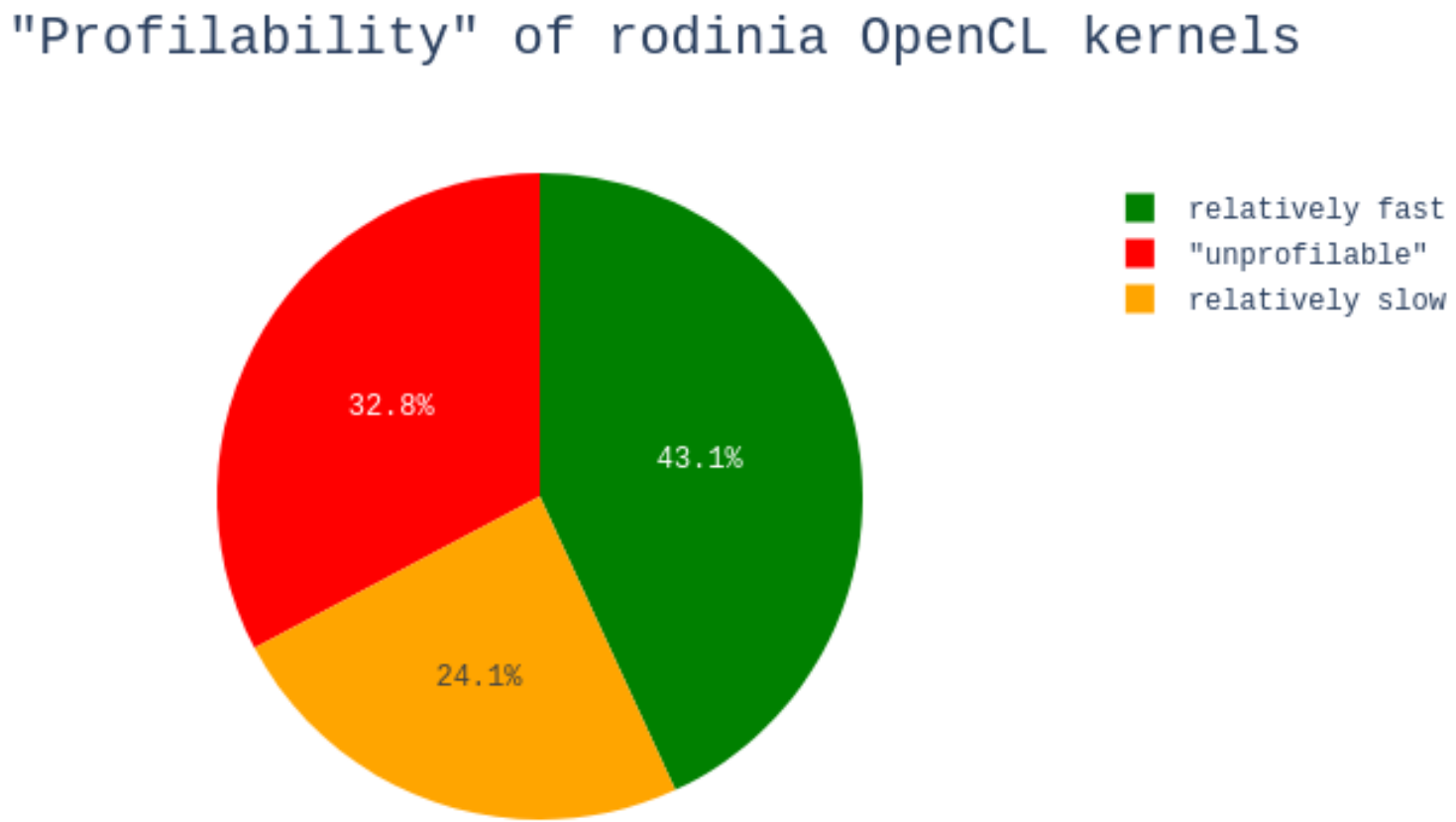
# Profiling kernels with oclude

- Why 100 samples?



# Exploratory data analysis on Rodinia measurements



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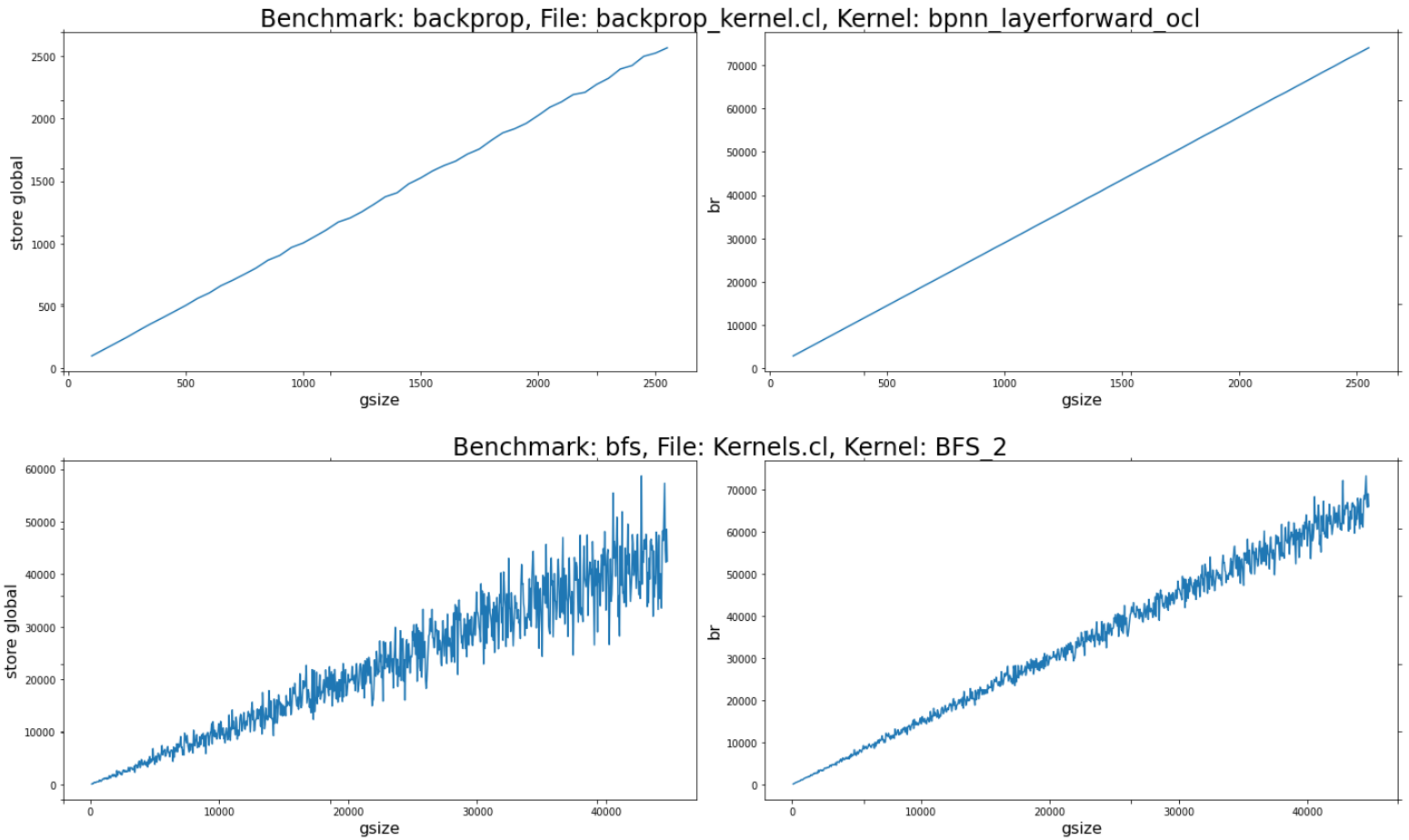
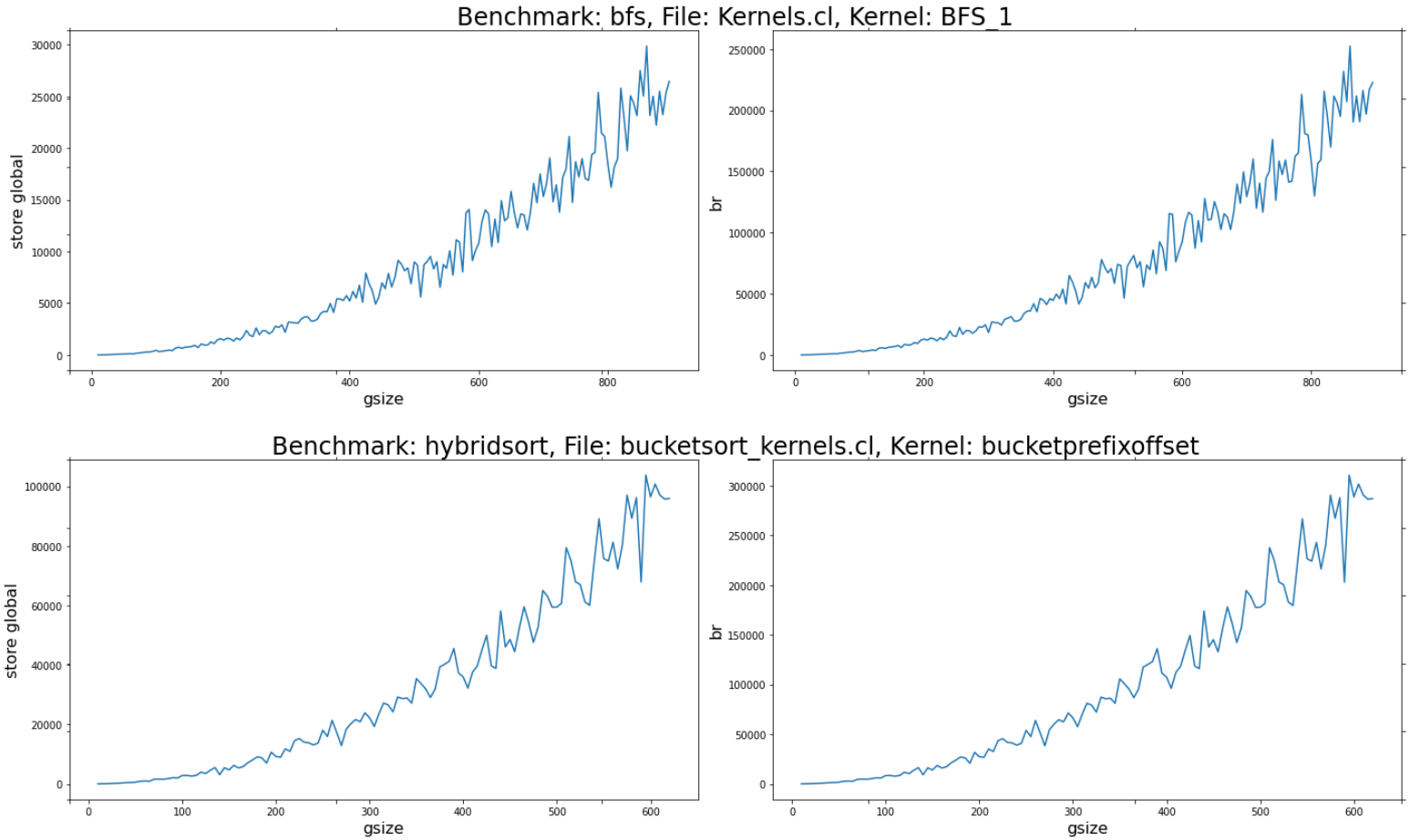
## Some "relatively fast" kernels



# Exploratory data analysis on Rodinia measurements

## Some "relatively slow" kernels



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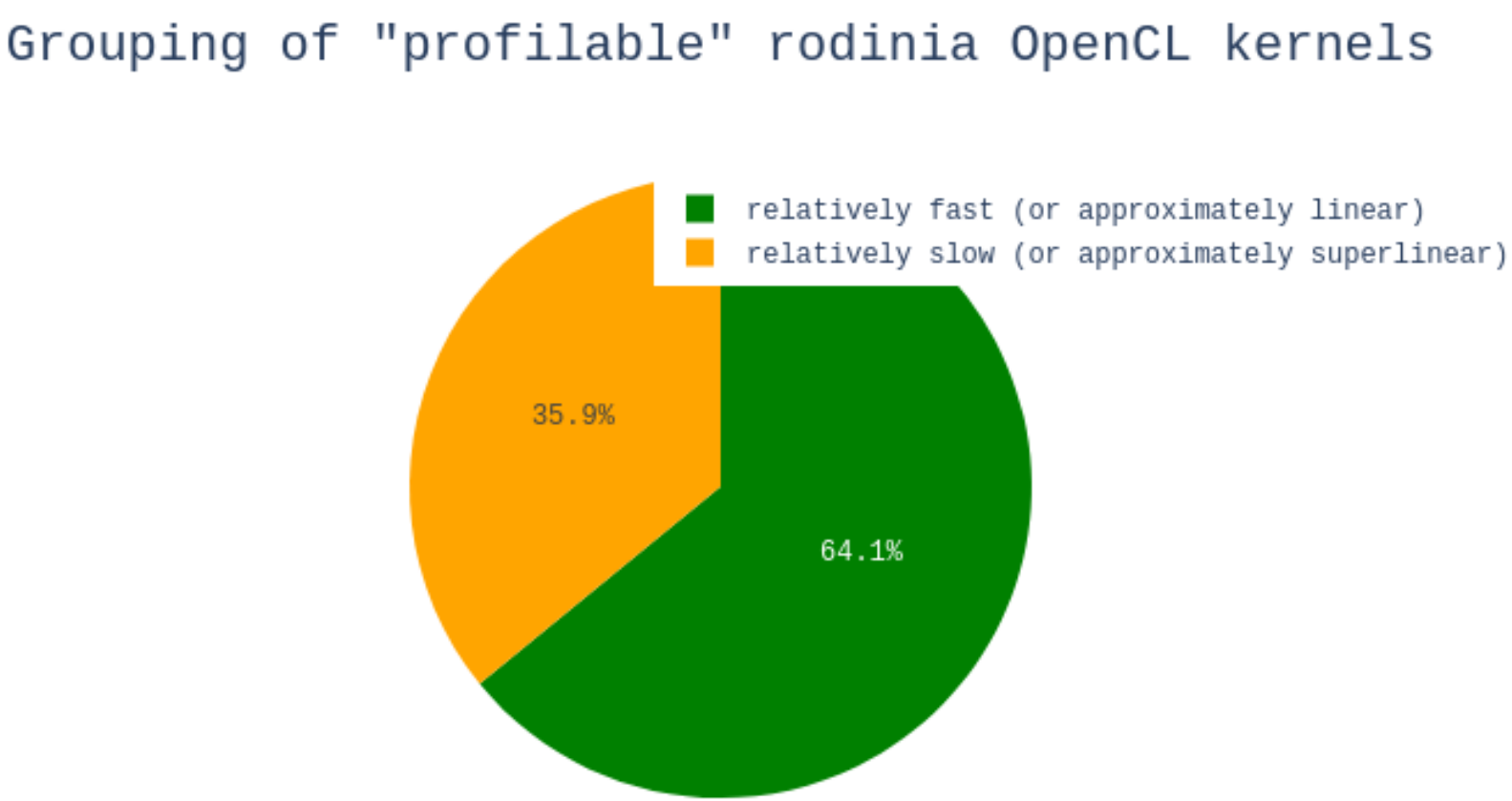

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- "relatively fast" $\rightarrow$ **linear relationship**
- "relatively slow" $\rightarrow$ **polynomial relationship up to degree 2**

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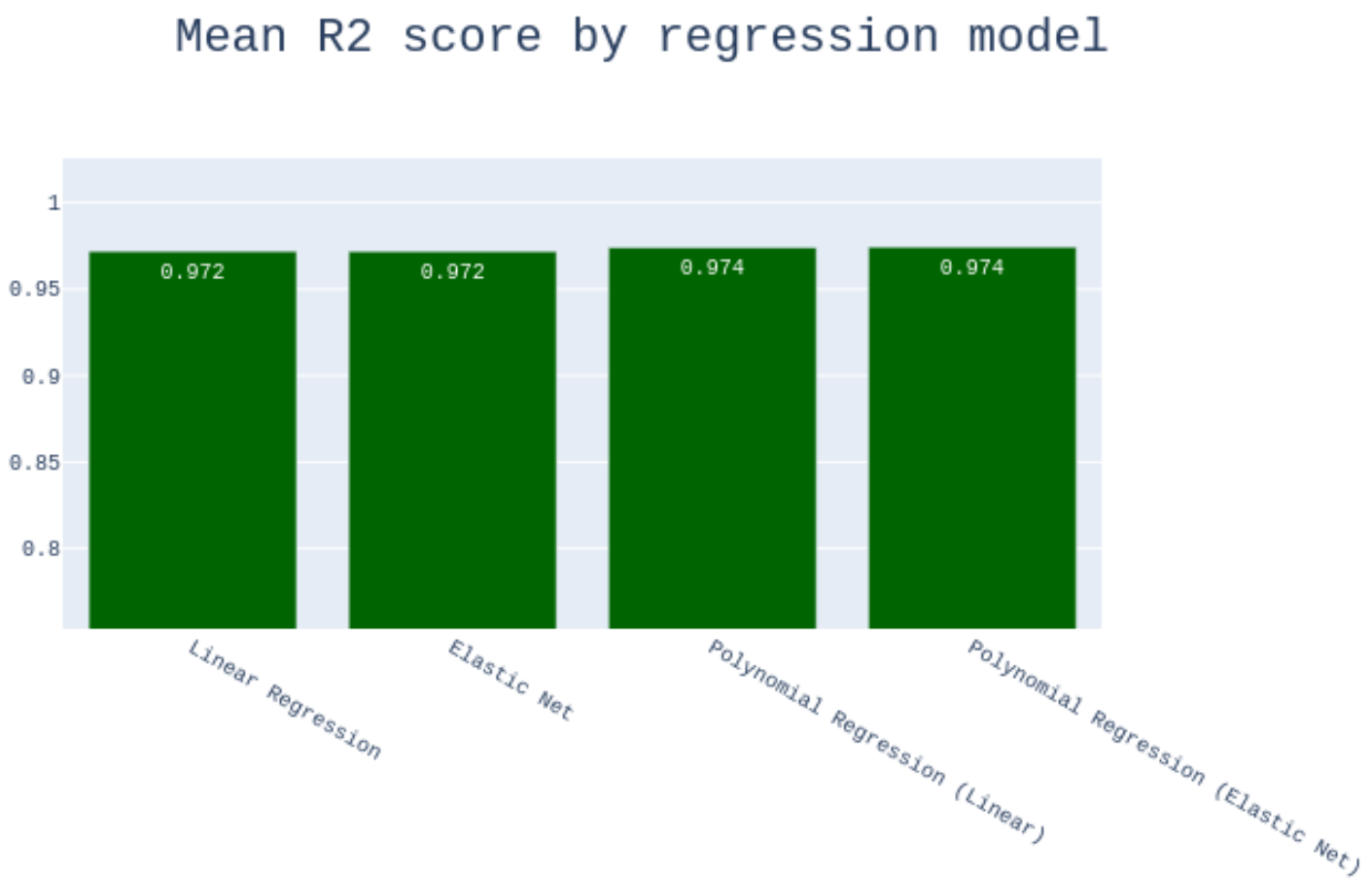
- predicts **instcounts** based on a **gsize** value
- training and testing on the measurements extracted from Rodinia via oclude
- the training/testing phase results in the selection (based on the $R^2$ score) of one of the following regression strategies:
  1. **Linear regression**
  2. **Elastic Net regression** (i.e. linear regression with L1 and L2 normalization penalties)
  3. **Polynomial regression of degree 2** based on linear regression
  4. **Polynomial regression of degree 2** based on Elastic Net regression

# OCLBoi and the Rodinia Suite



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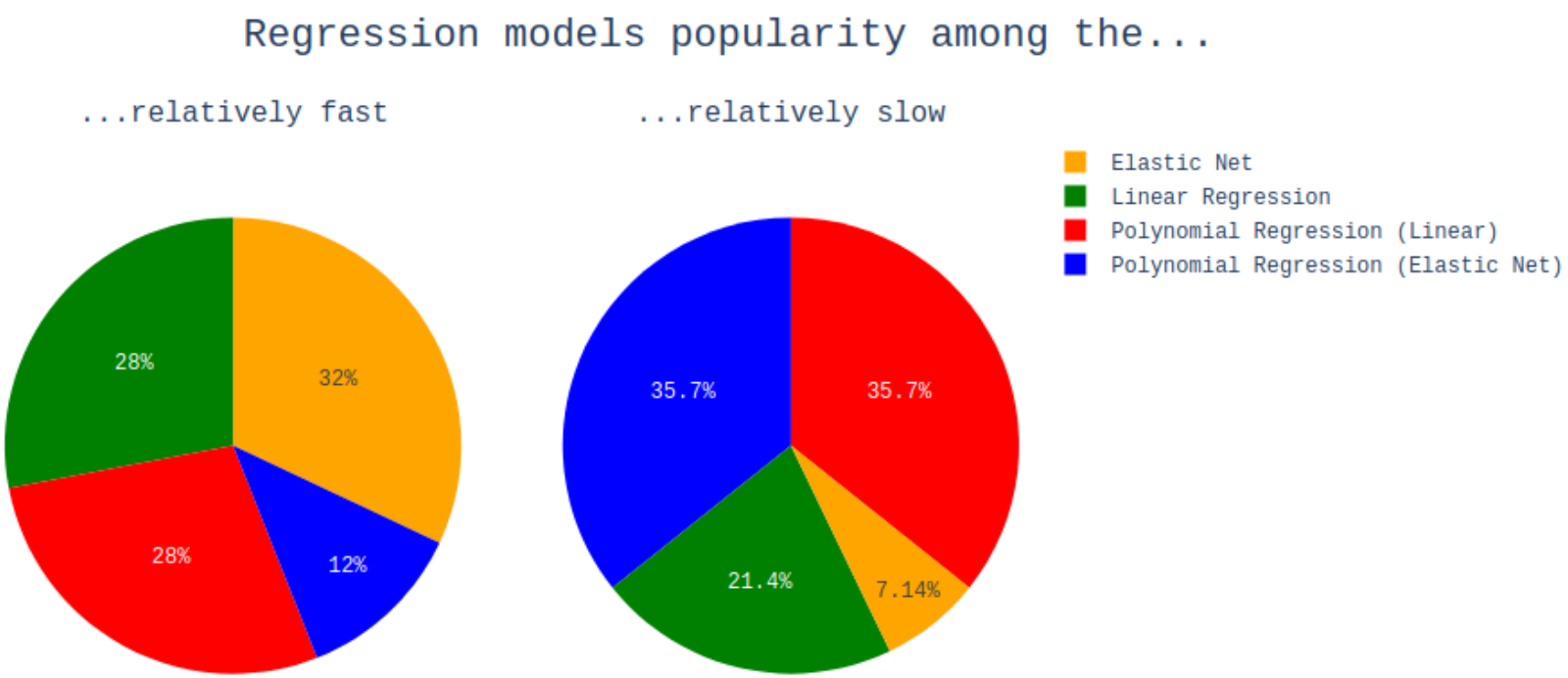

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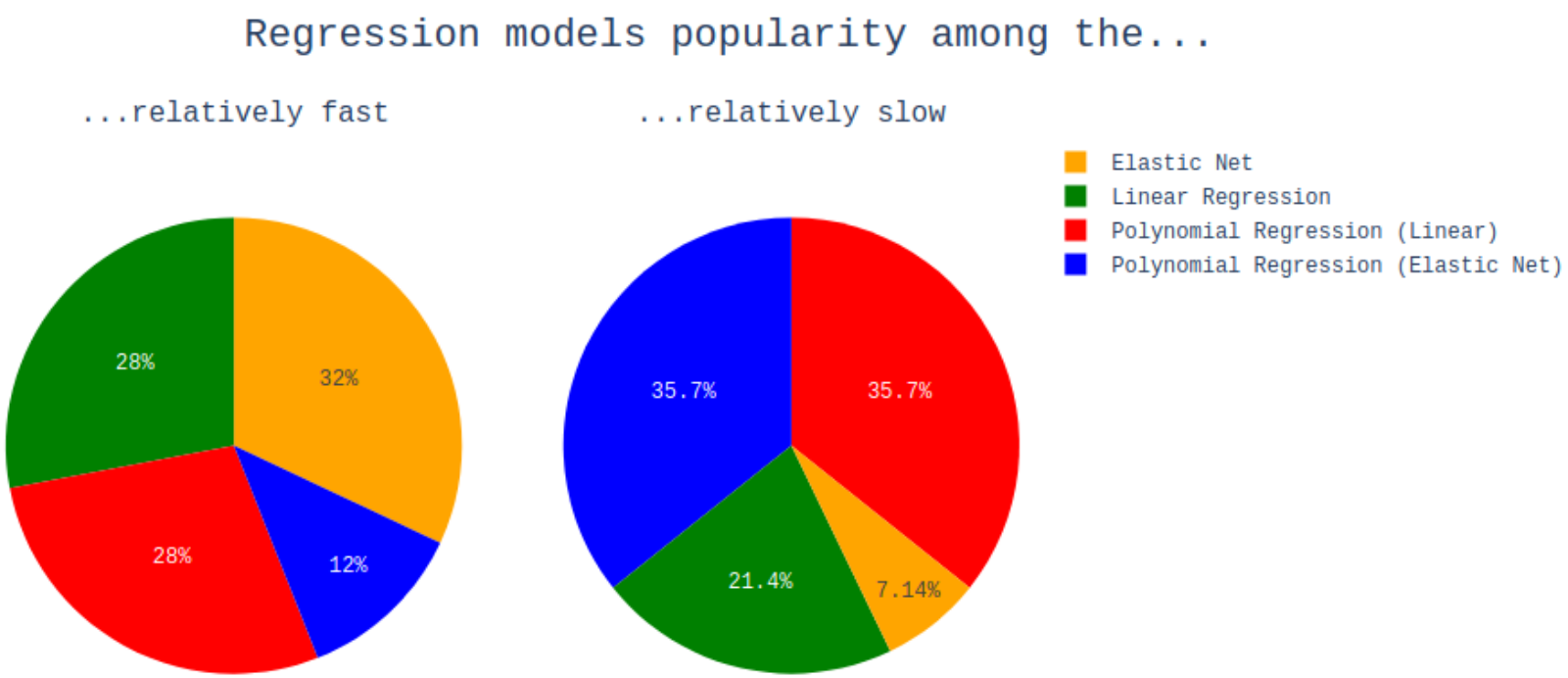
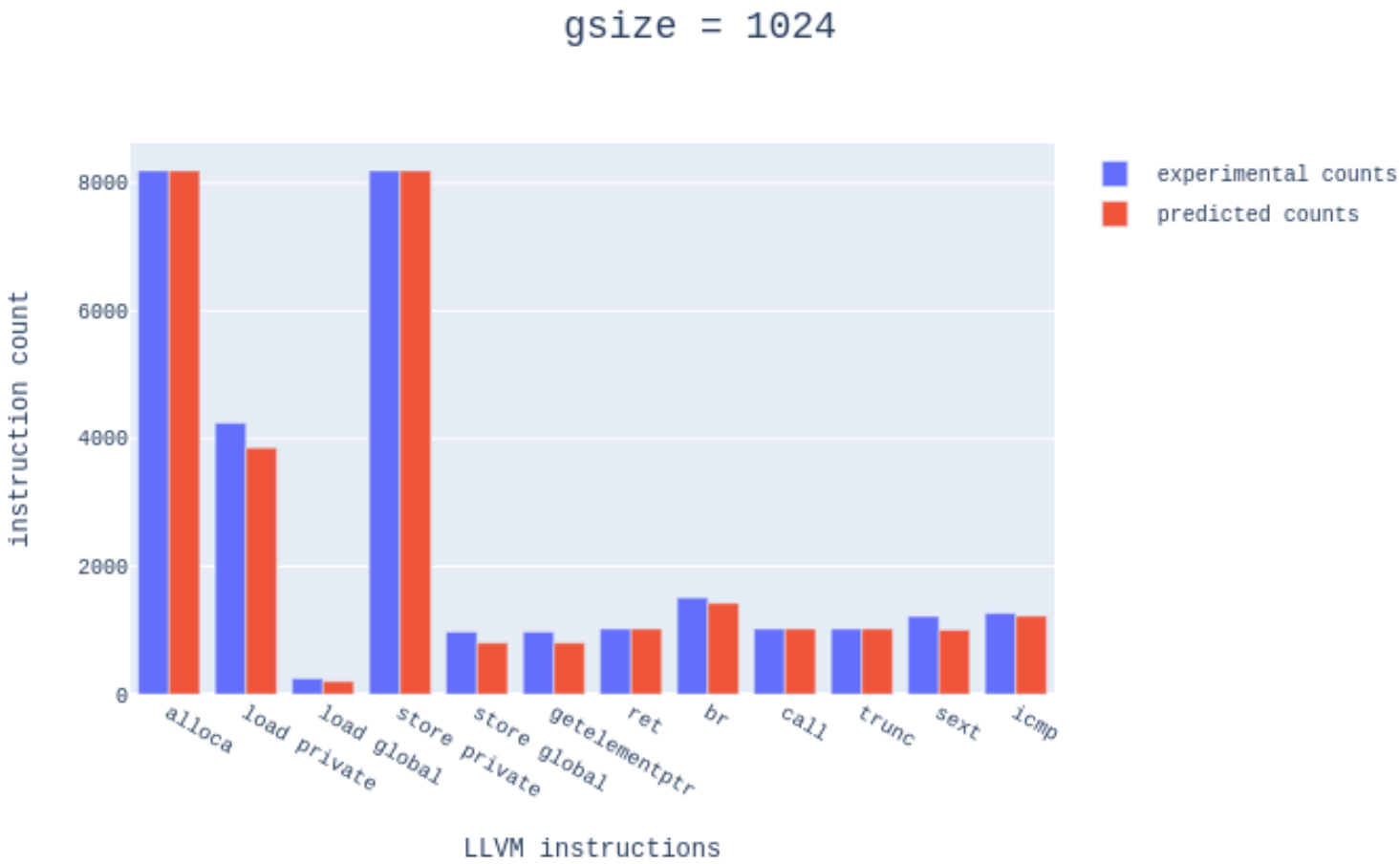



- "relatively fast" $\rightarrow$ **linear models** (60%)
- "relatively slow" $\rightarrow$ **polynomial models** (71.4%)

# OCLBoi in action



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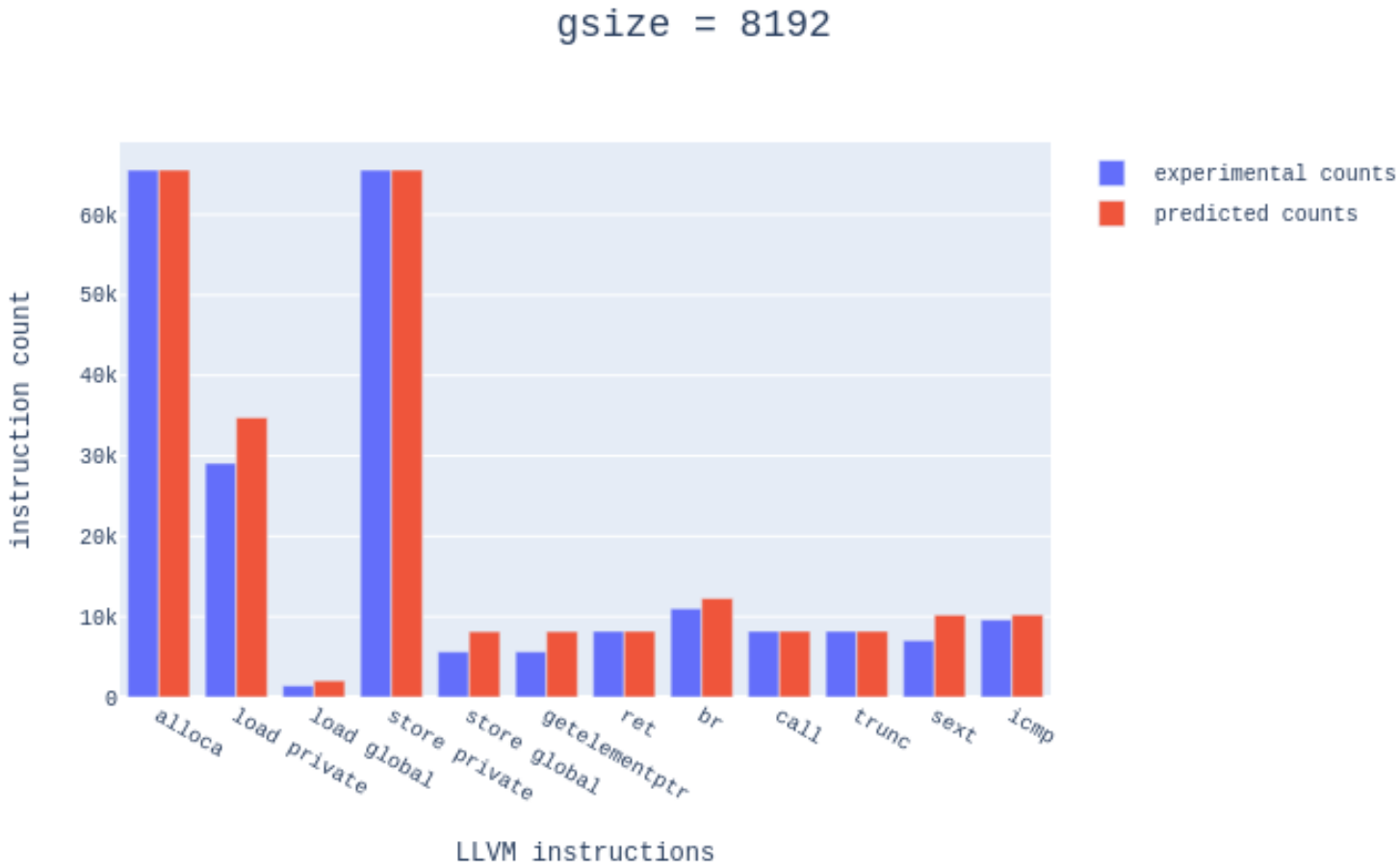

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By predicting execution time!

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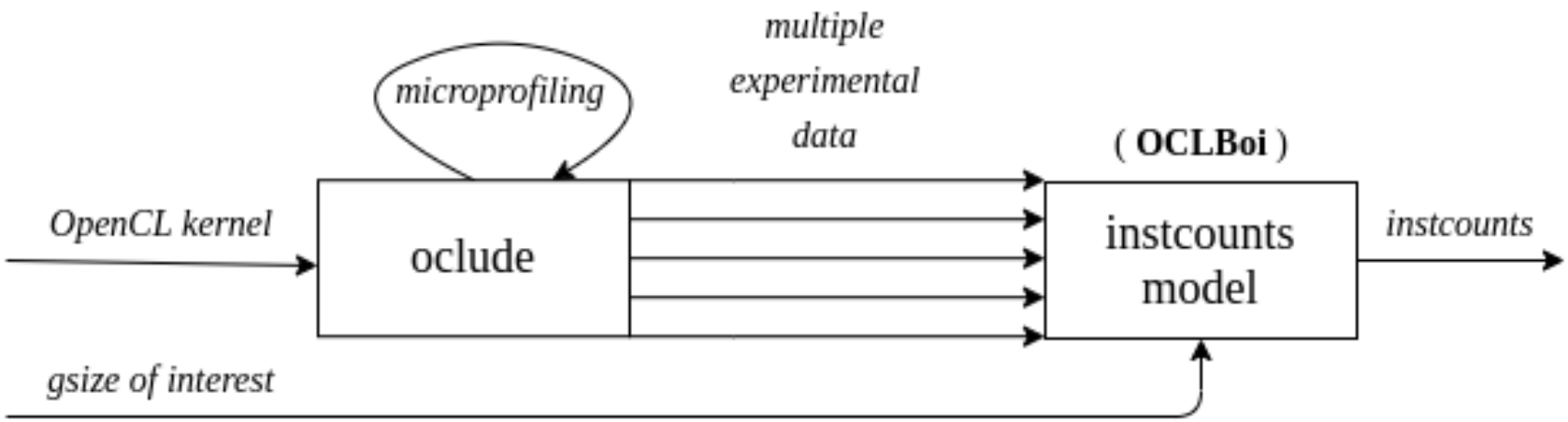

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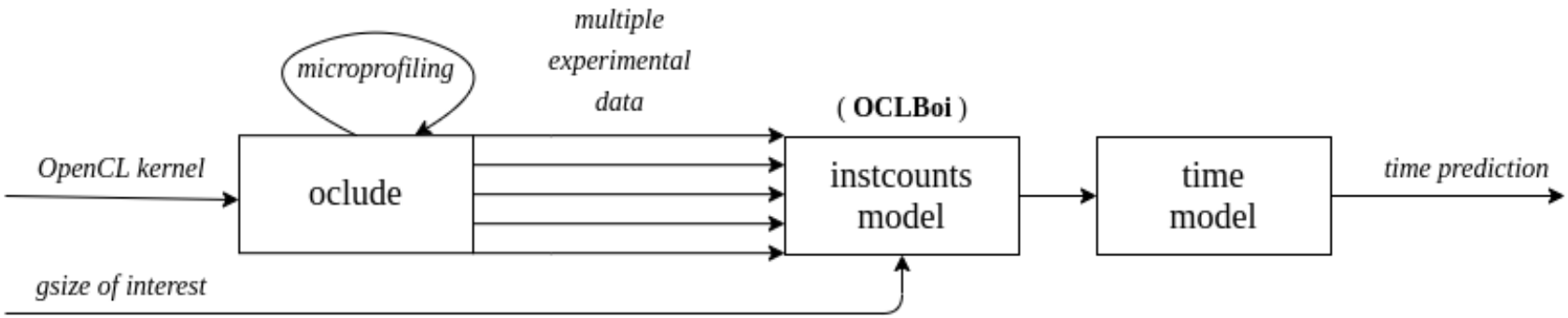

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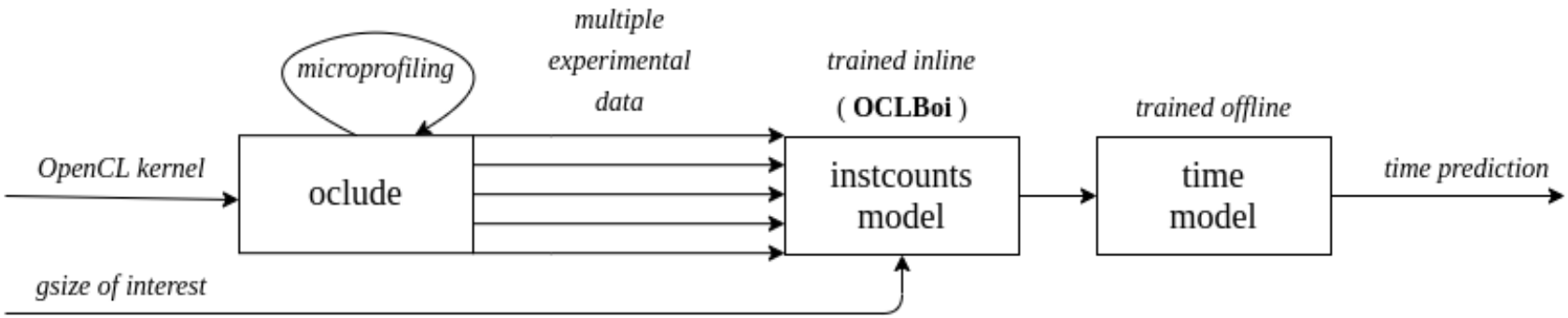

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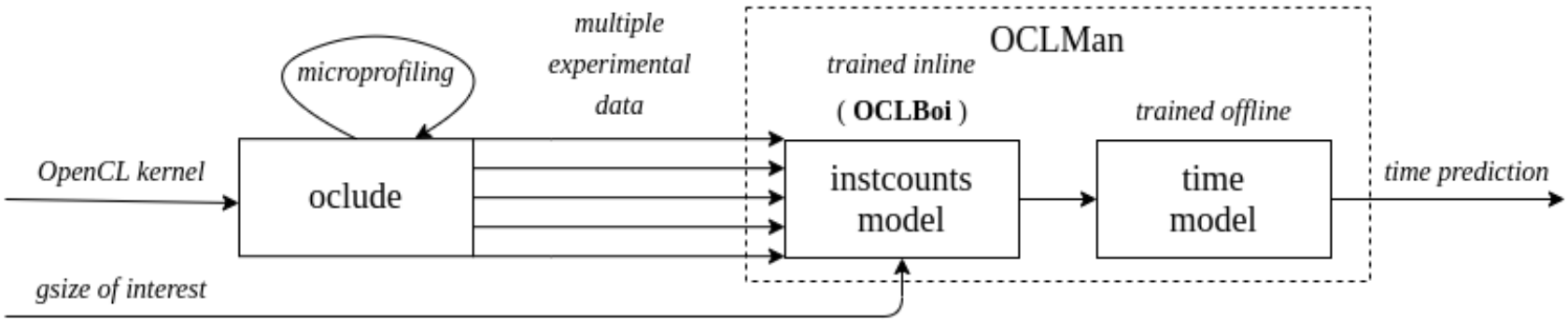

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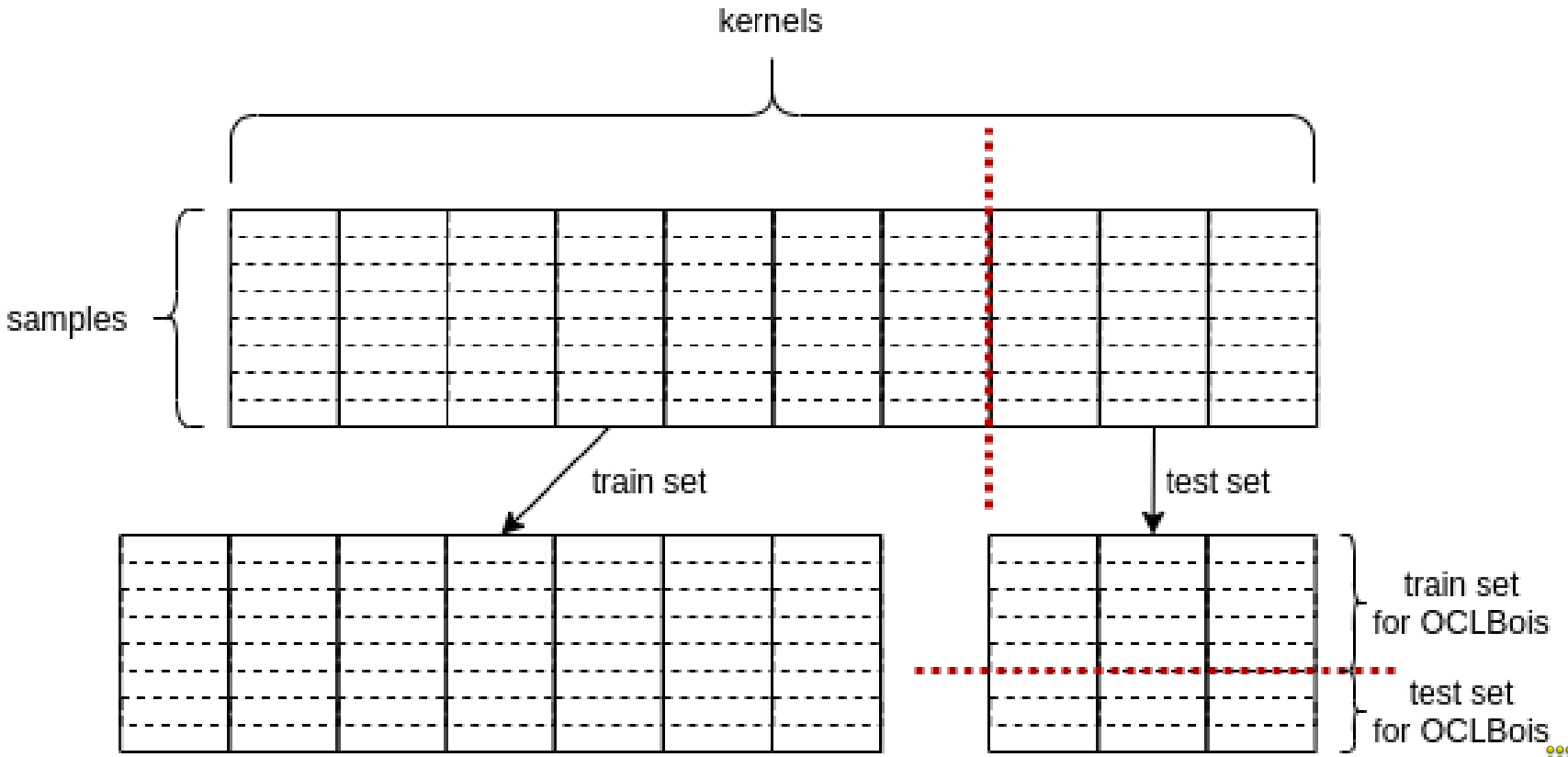
  4. ...and we have a prediction!

# OCLMan training



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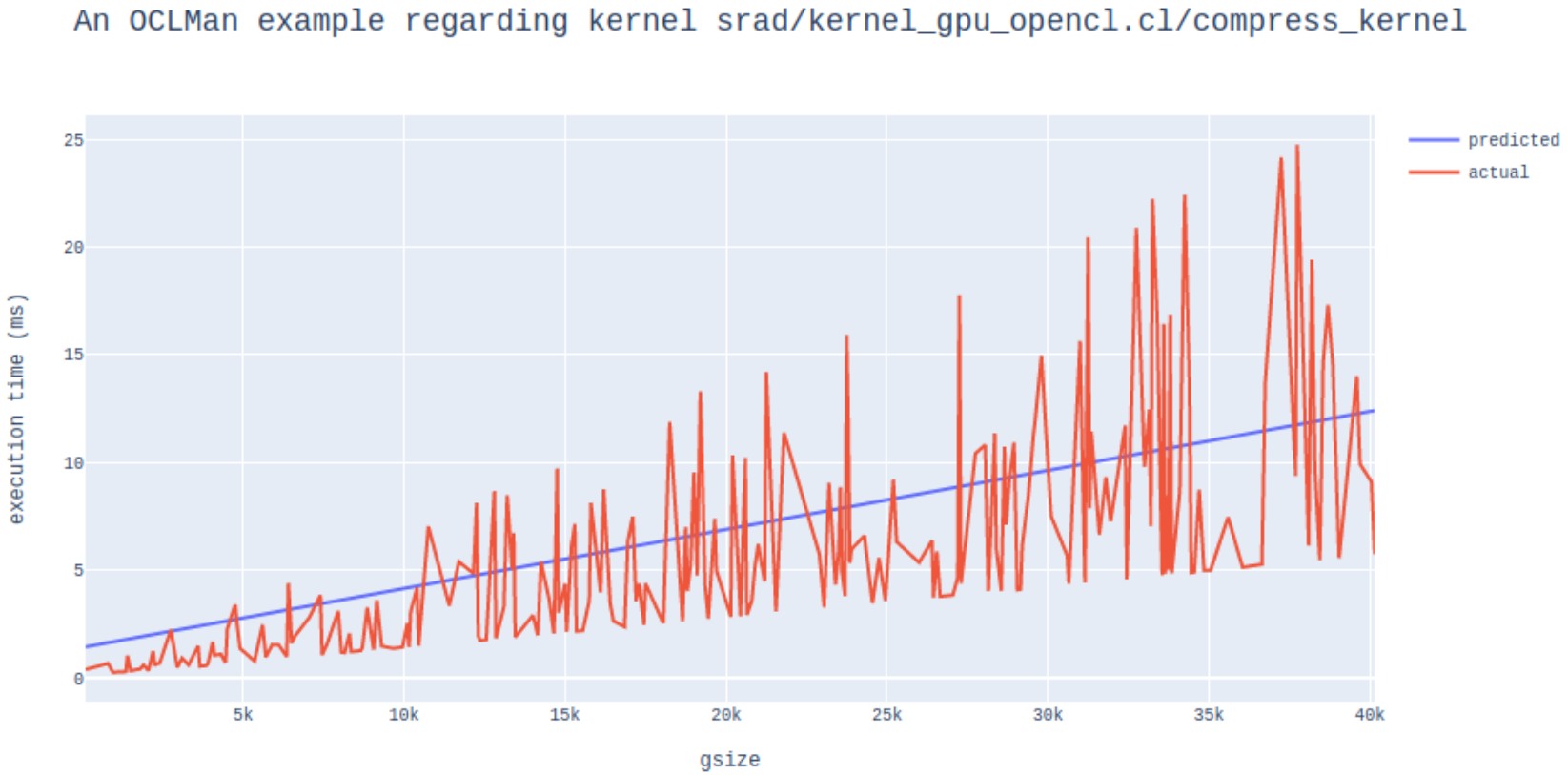

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**Let's build one!**

To build it, we will simply **replace dynamic instcounts with the static ones** of the kernel

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## Assumption 2

$$gsize \longmapsto instcounts : (at\ most)\ polynomial,\ proven$$
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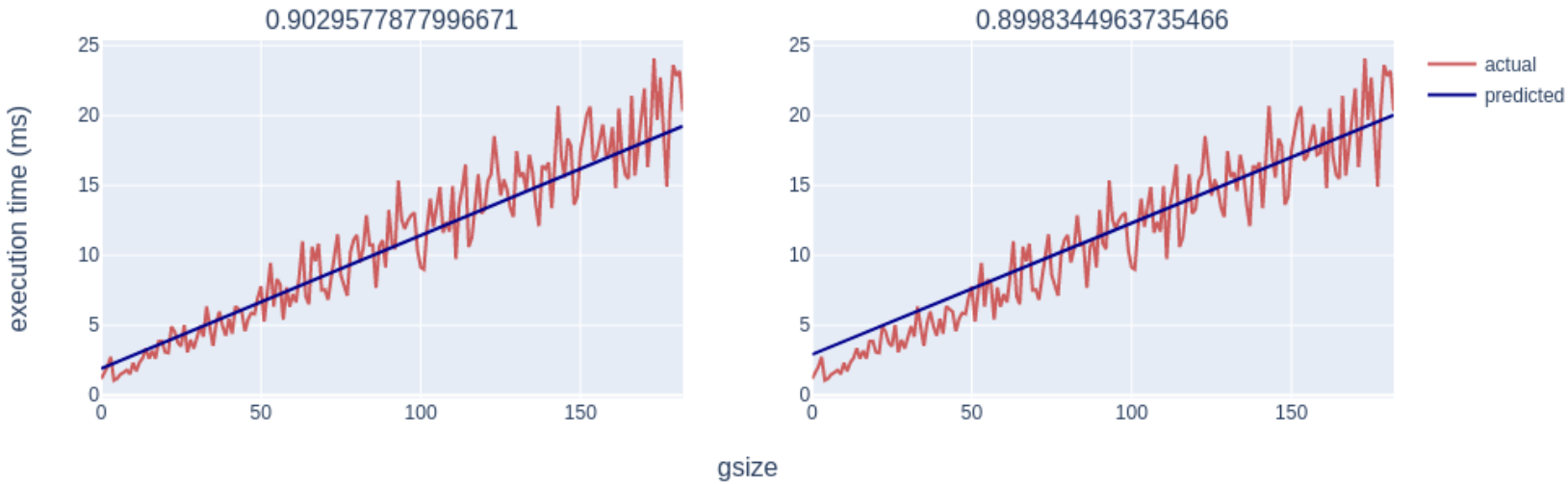

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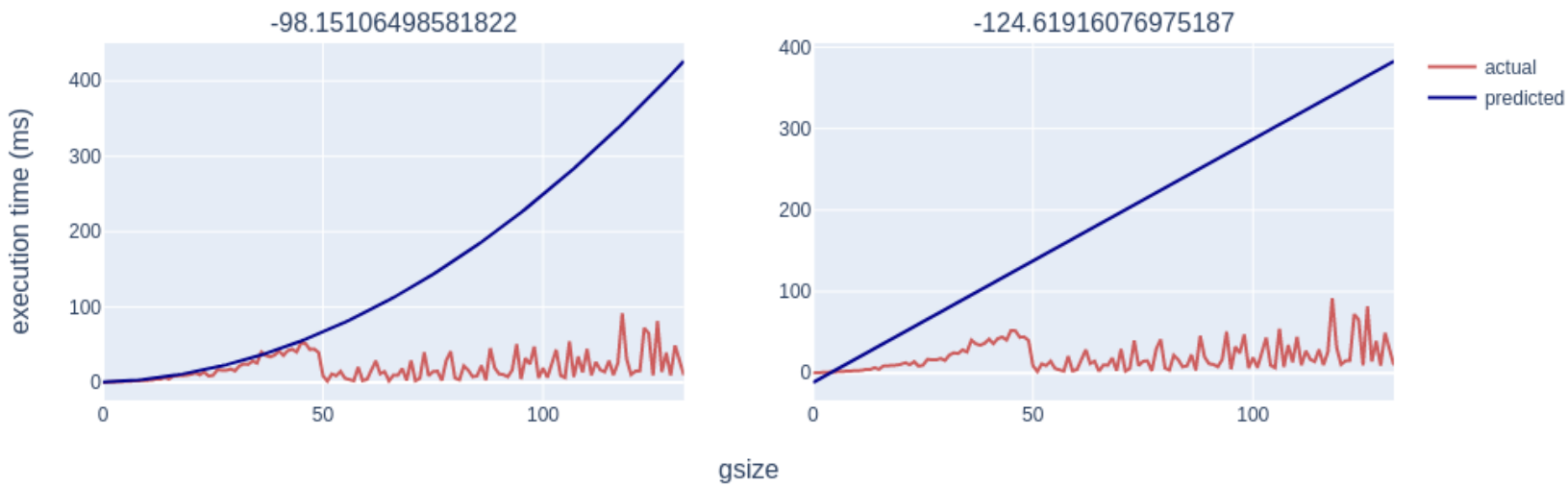

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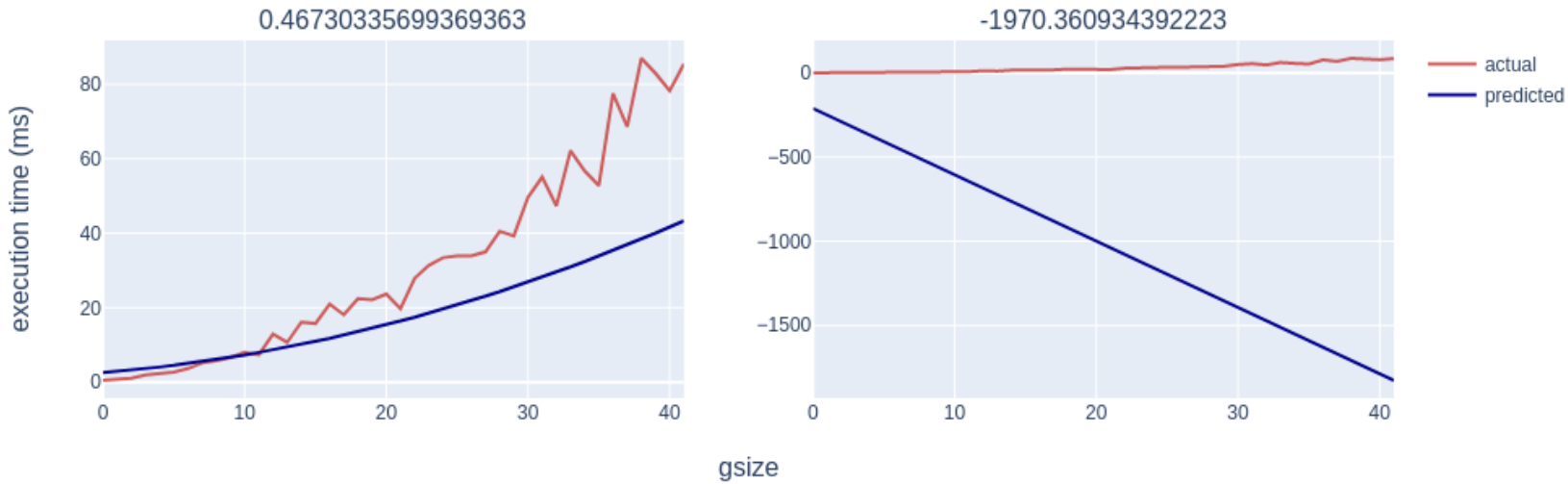

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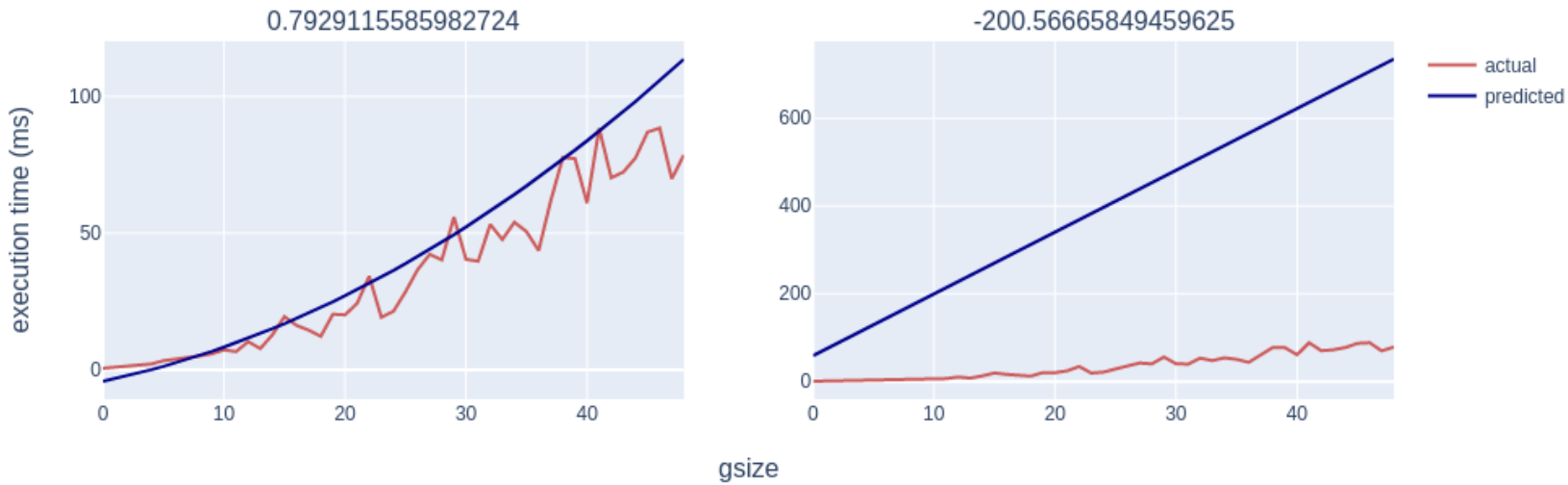

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- These results mean that:
  1. `oclude` extracts **valuable dynamic information** that surpasses the static approach
  2. `OCLMan` and its `OCLBois` manage to **capture that additional information** and **make something useful out of it**.

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*Thank You!*