Nugget:
Portable Program Snippets

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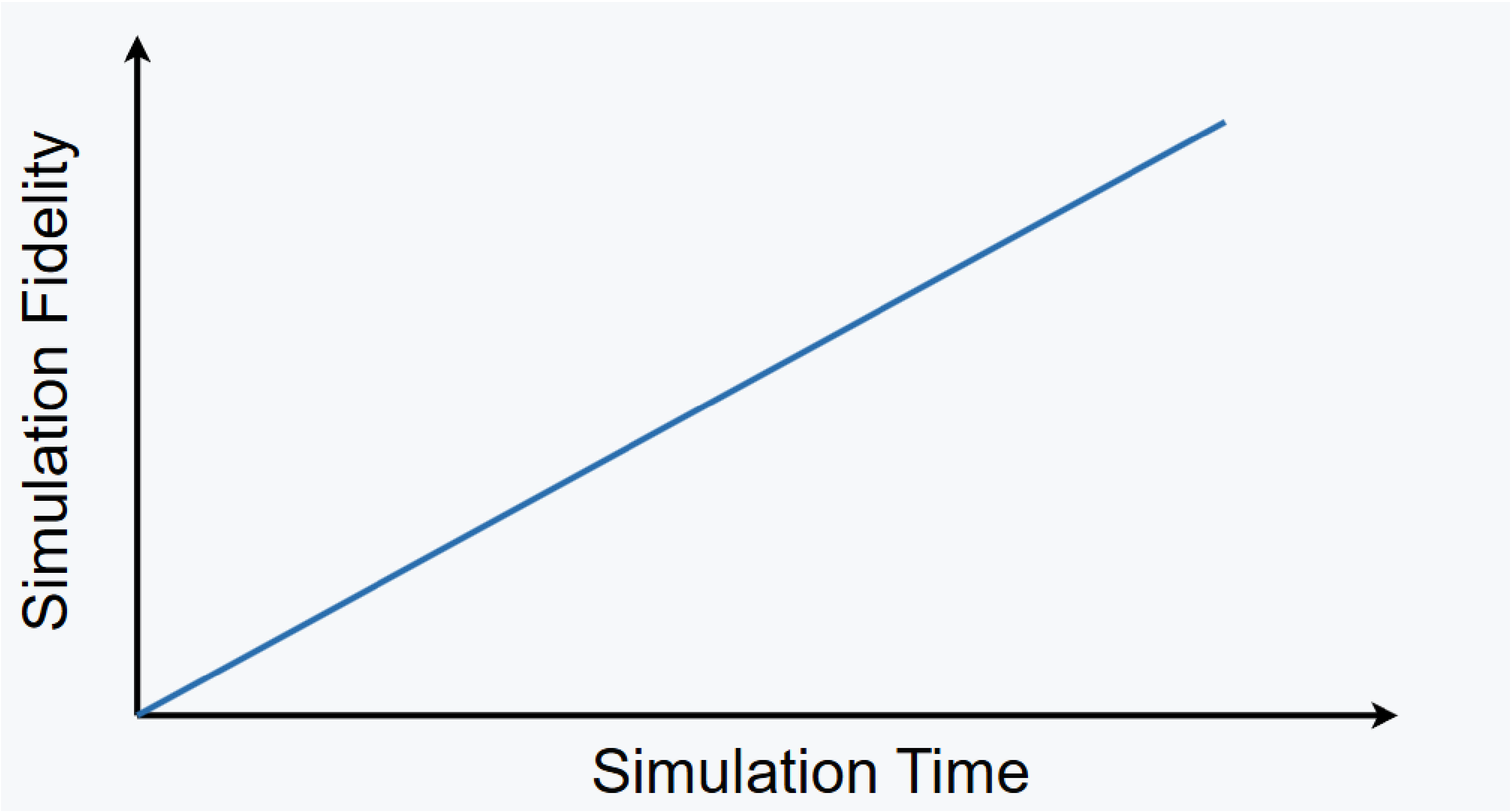
Outline

1. Background and Motivation
2. The Nugget Framework
3. Evaluation
4. Conclusion

Background and Motivation

Problem: High fidelity simulation implies long simulation time

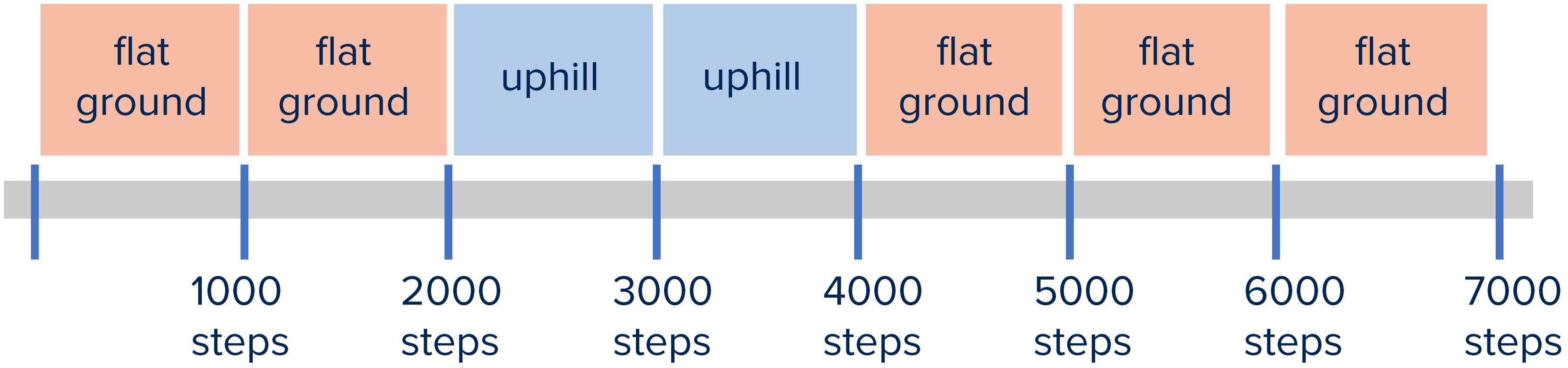


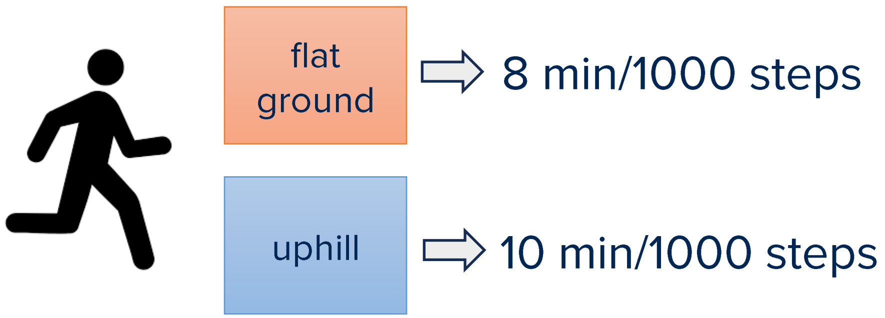
What are the solutions to long simulation time?

- Reduce simulation fidelity
- Reduce workload
  - ➢ Use sampling methodologies
    - Two major types:
      1. **Targeted sampling**
      2. Statistical sampling

Targeted Sampling

Representative methodologies: SimPoint, LoopPoint

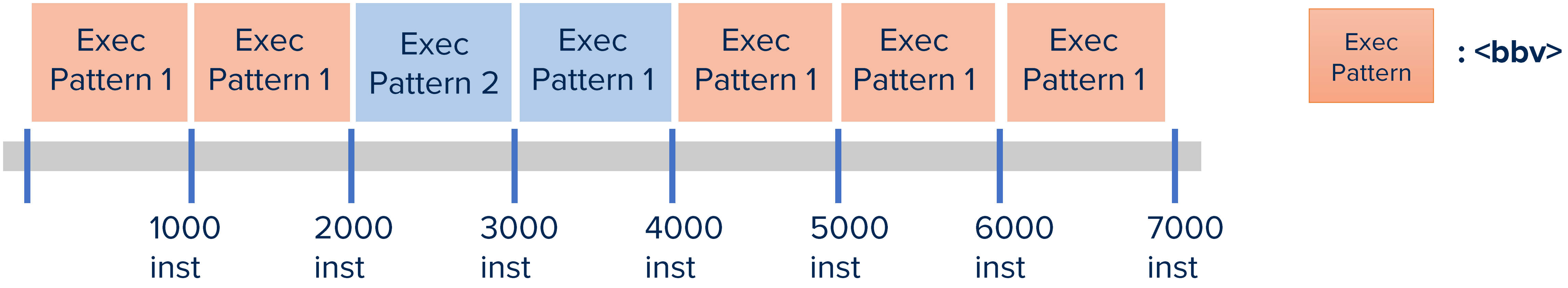


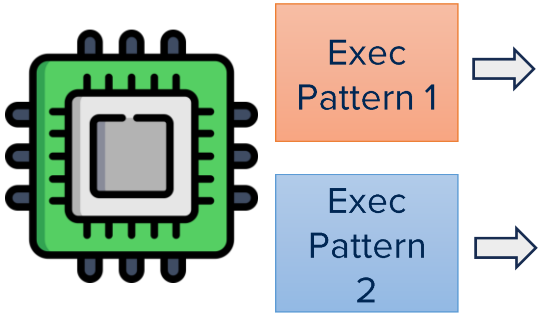


Their predicted runtime for this path is
5 x 8 min + 2 x 10 min = 60 min

Targeted Sampling

Representative methodologies: **SimPoint**, LoopPoint





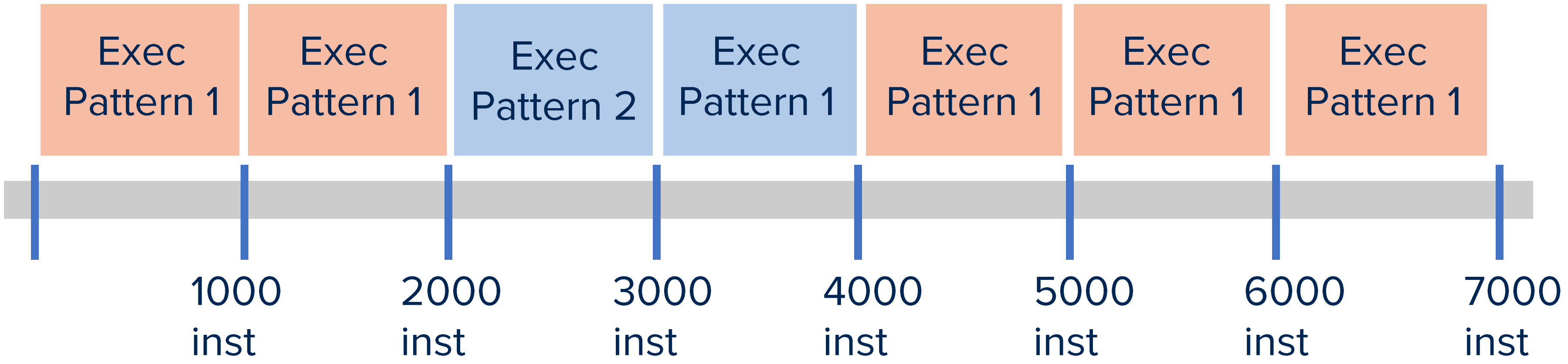
Runtime: X = CPI_1 * 1000 * 1/f

Runtime: Y = CPI_2 * 1000 * 1/f

Their predicted runtime for this program is **5 x X + 2 x Y**

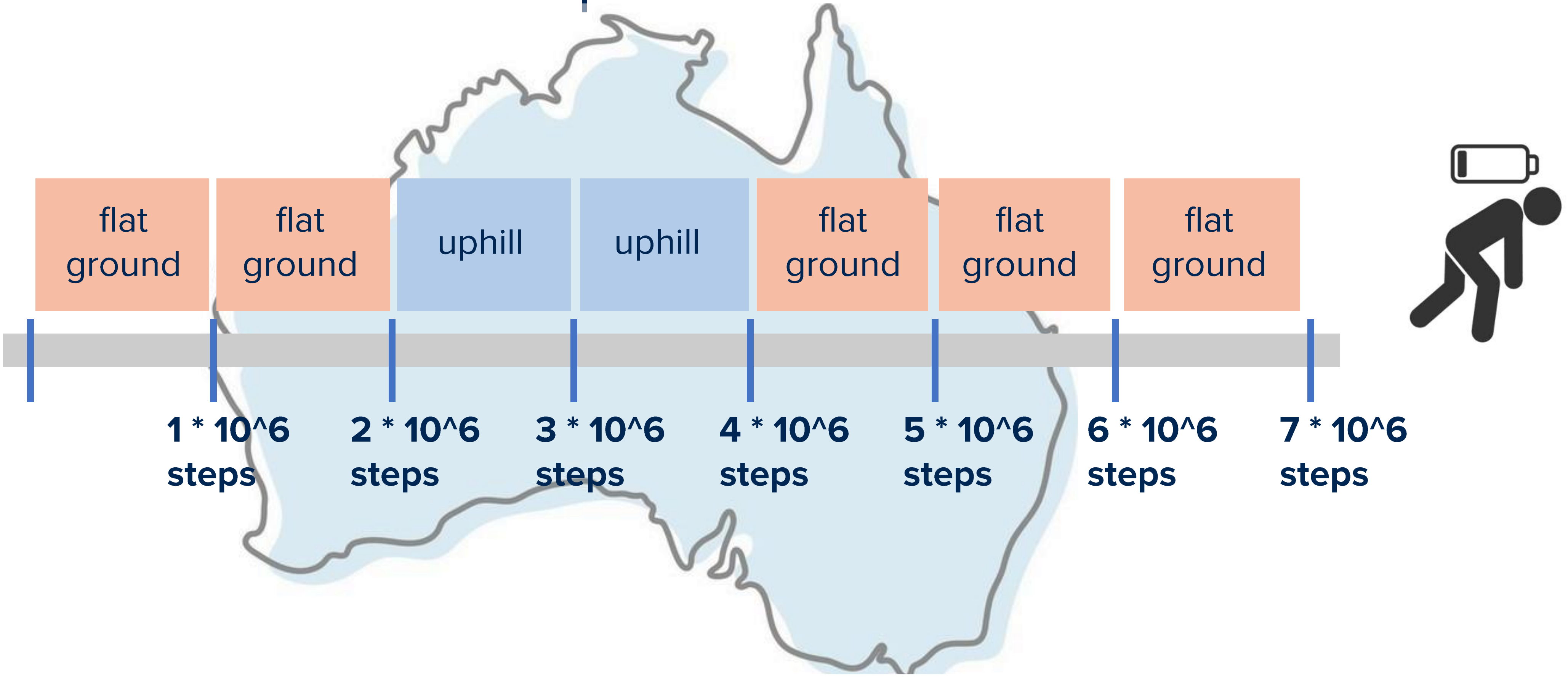
Targeted Sampling

Representative methodologies: SimPoint, LoopPoint



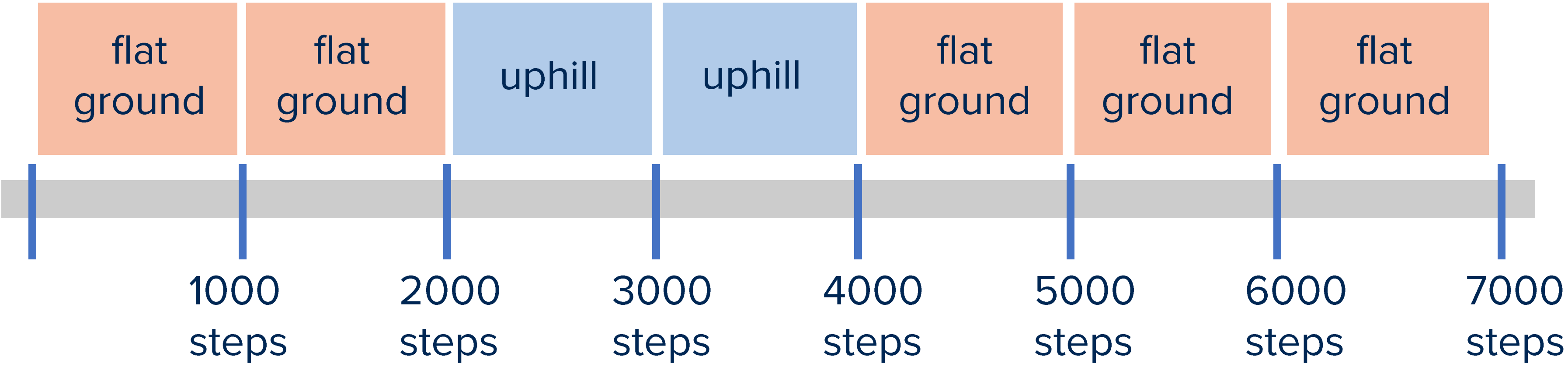
Targeted sampling selects samples based on specific characteristics that are discovered by **analysis**.

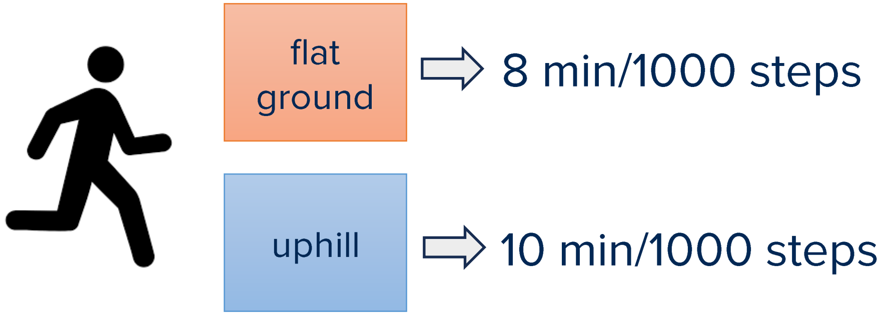
Drawbacks of prior works

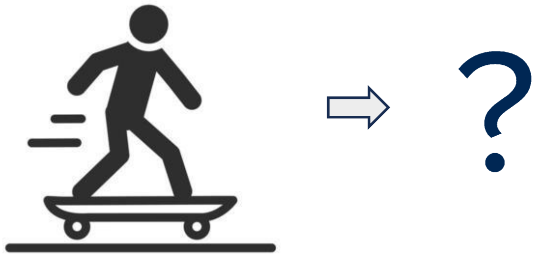


1. **Samples are expensive to find**
   - Simulators are too slow
   - Dynamic tools lack ISA support / host flexibility

Drawbacks of prior works



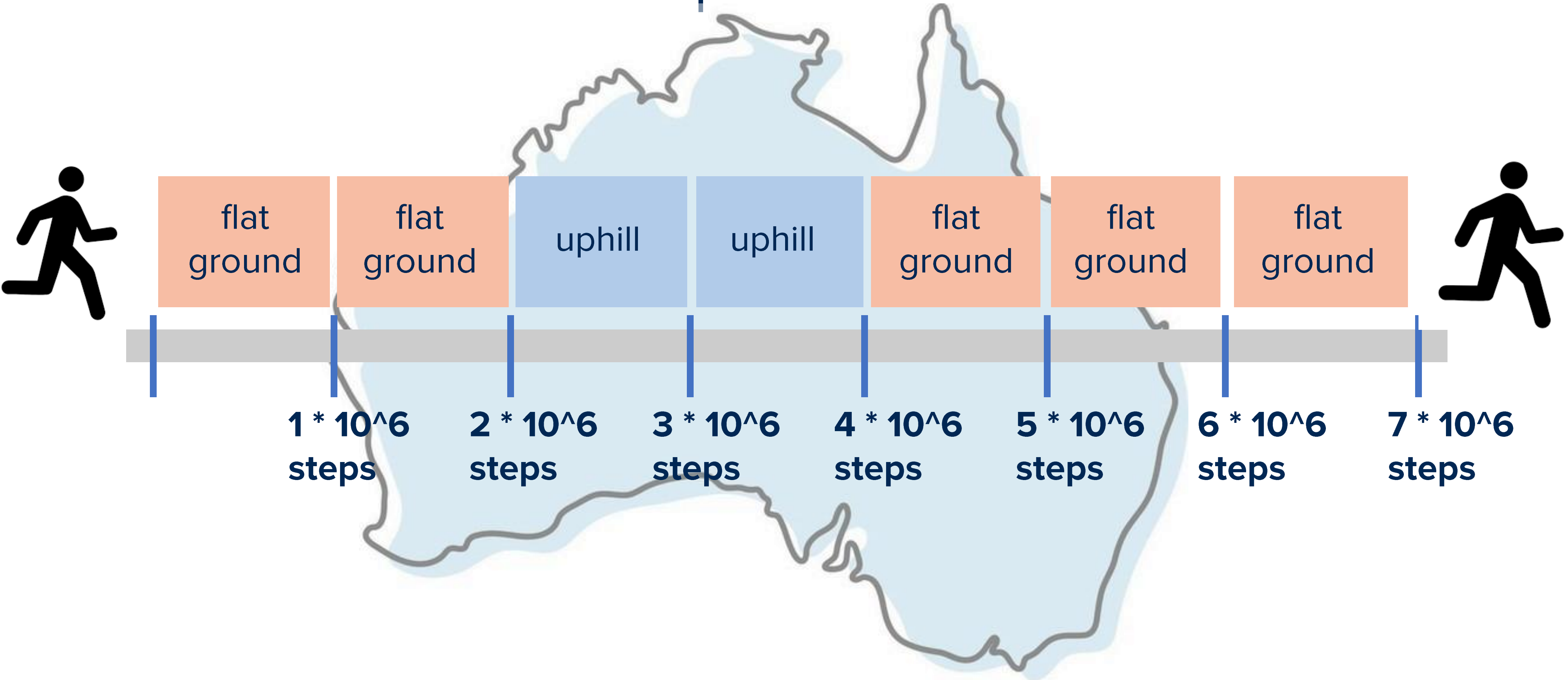




2. Samples are tied to a single executable binary

- Recompile = reselect samples

Drawbacks of prior works



3. Validating the selected samples is infeasible

- Use simulation to get ground truth is infeasible

Drawbacks of prior works

Drawbacks	Prior Works: SimPoint, LoopPoint
Samples are expensive to find	Rely on **tool / simulation** to analyze program ✗
Samples are tied to a single executable binary	Rely on **machine level instruction** to define interval ✗
Validating the selected samples is infeasible	Rely on **slow simulation** to validate samples ✗

Drawbacks of prior works

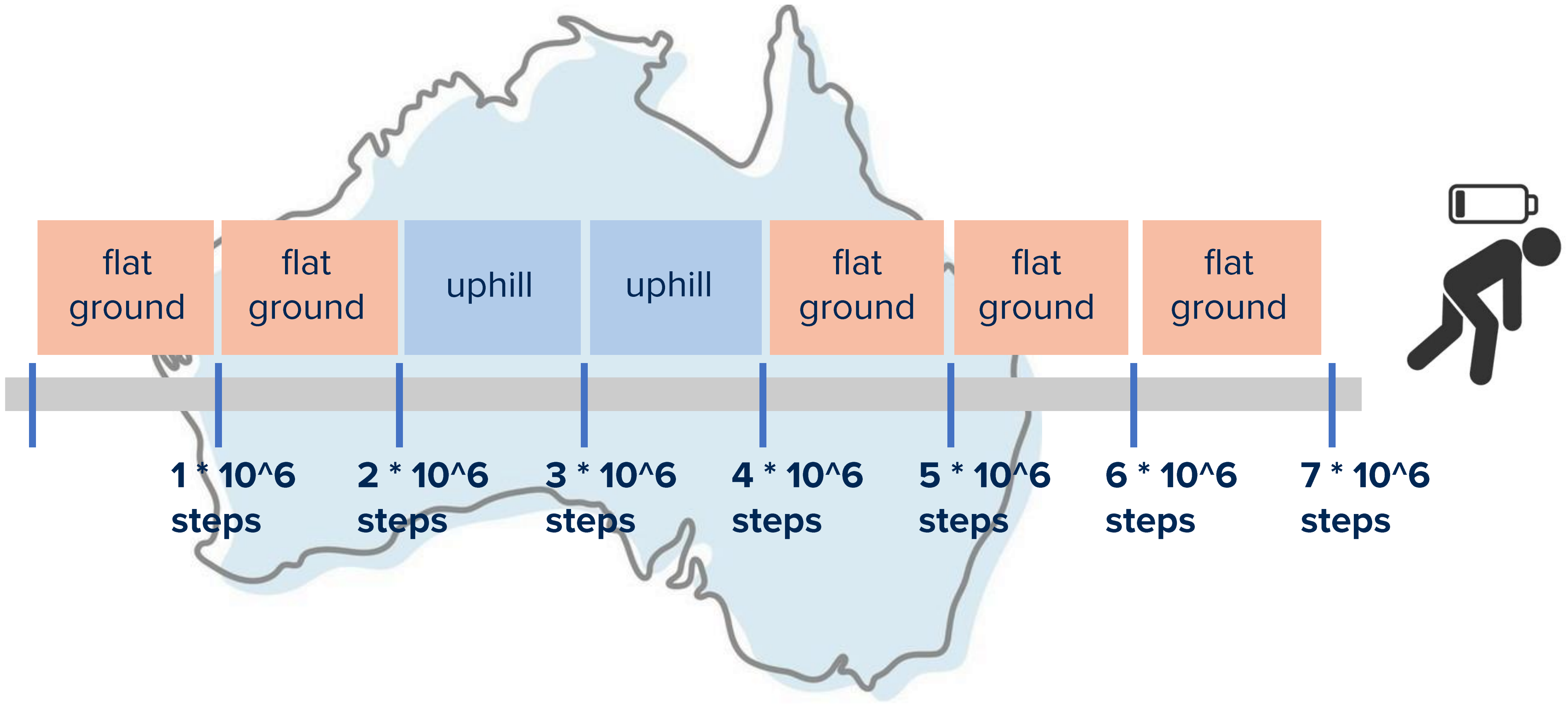
Drawbacks	Prior Works: SimPoint, LoopPoint
Validating the selected samples is infeasible	Rely on **slow simulation** to validate samples

These drawbacks make the sampling process **slow and effectively a black box.**

The Nugget framework's goals

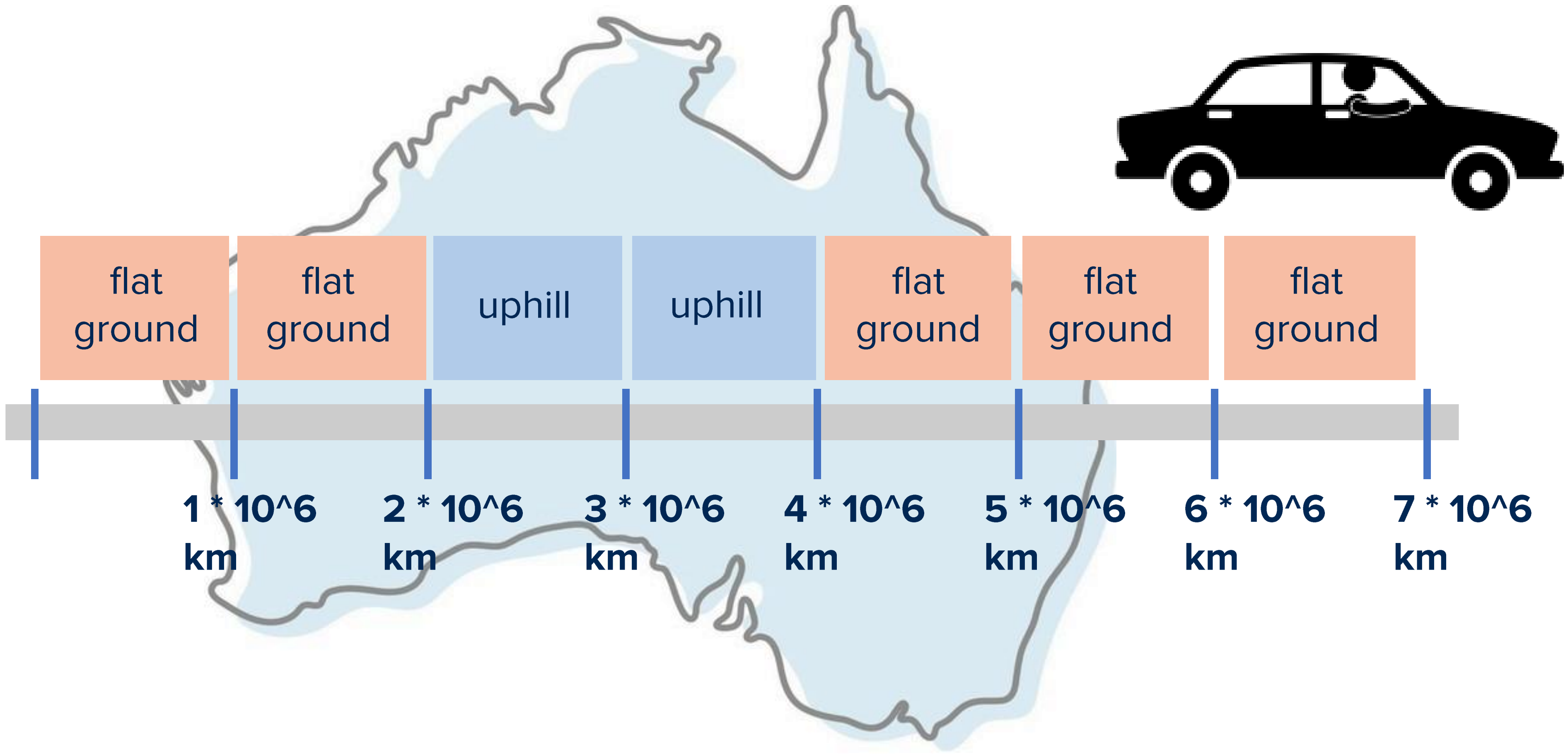
1. **Make finding samples fast**
   - Analyzing program execution quickly and without restrictions on architecture or host machine
2. **Make samples decoupled from a single executable binary**
   - Automatically generating samples that are independent of the binary
3. **Make validating the selected samples feasible**
   - Quickly validate the selected samples for the targeted benchmarks and input size

Connect the example with Nugget



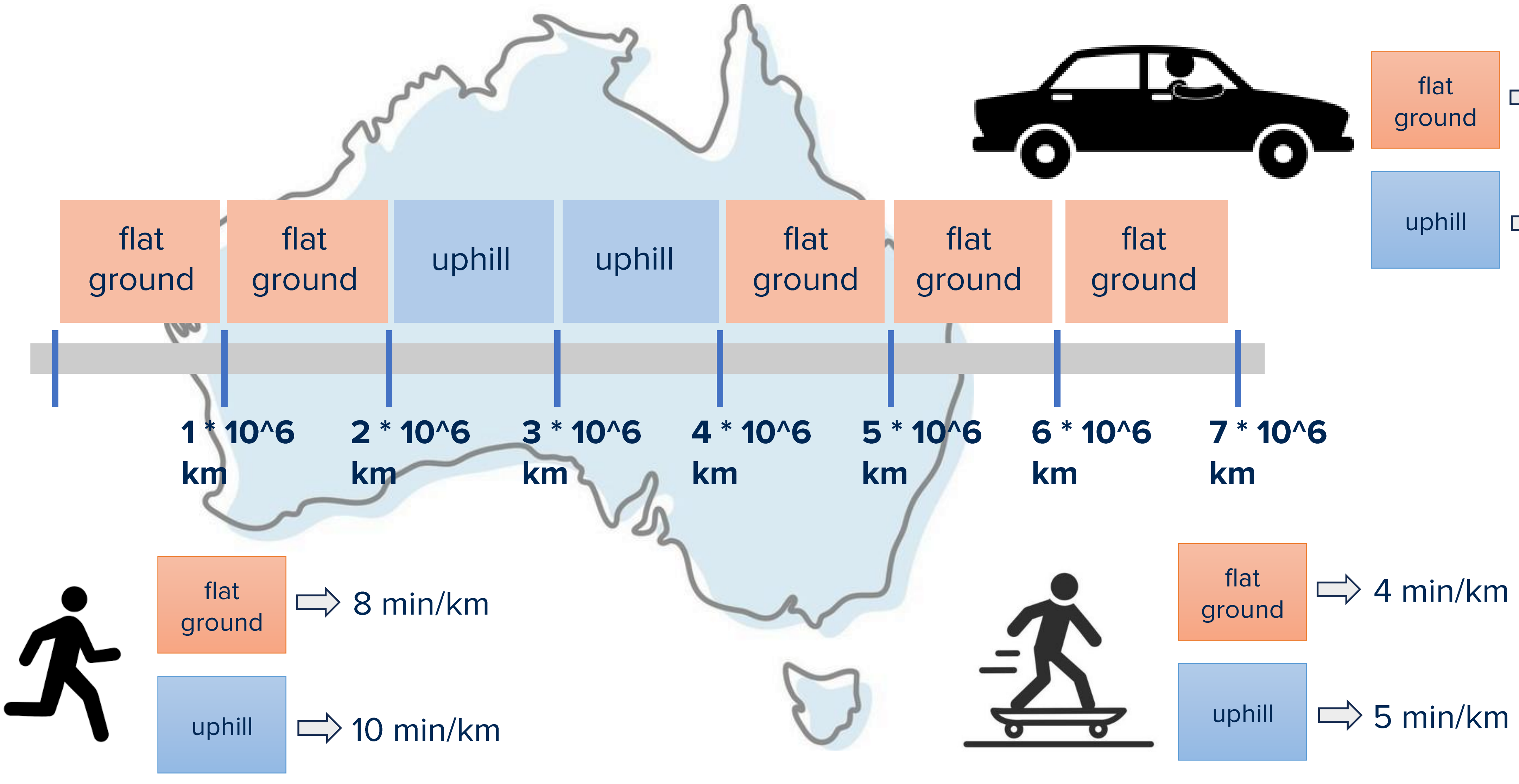
If the unit is step,
we have to step through the path

Universal unit enables faster analysis method

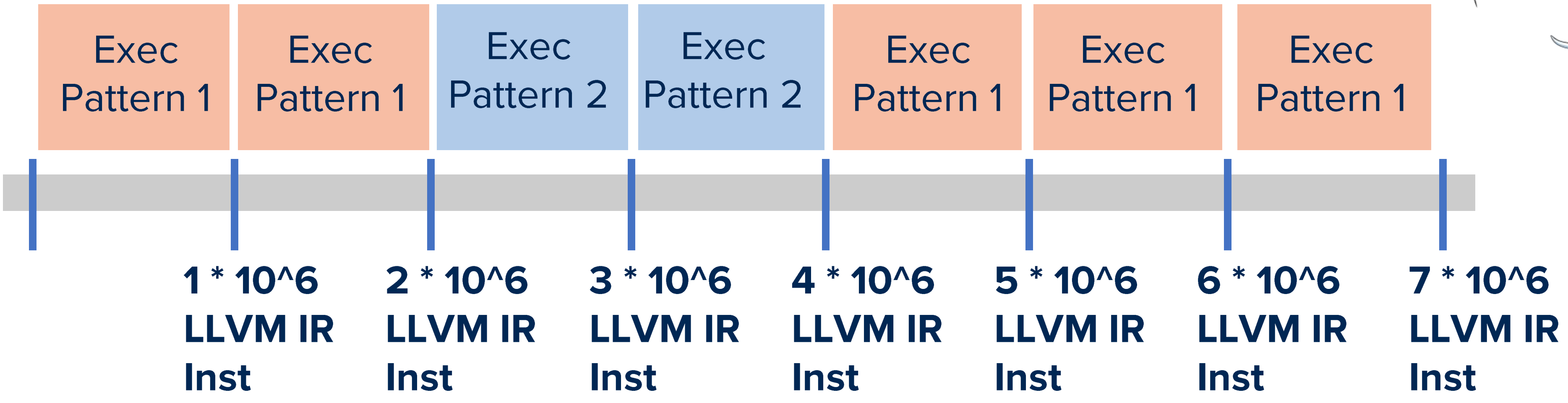


If the unit is km instead of step,
we can use faster method to measure km

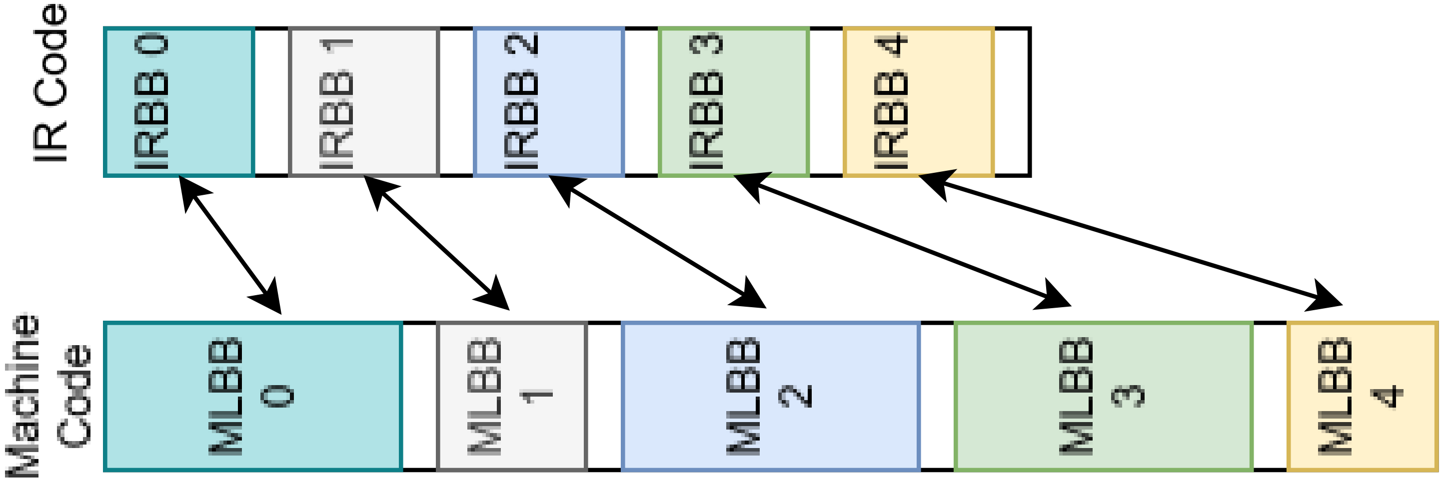
Universal unit enables cross platform samples



In Nugget's case



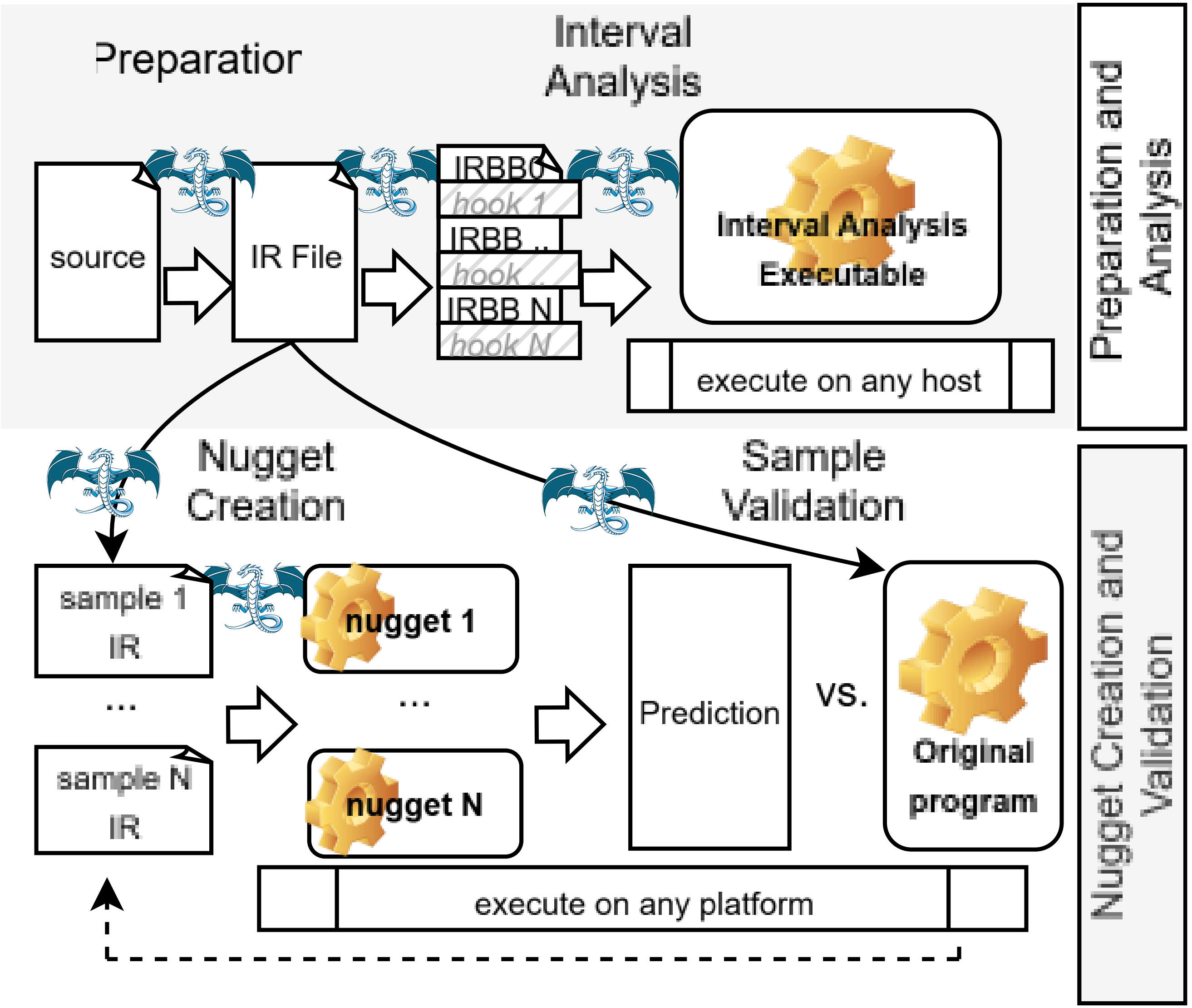
LLVM Intermediate representation (IR) is our universal unit.



The Nugget framework

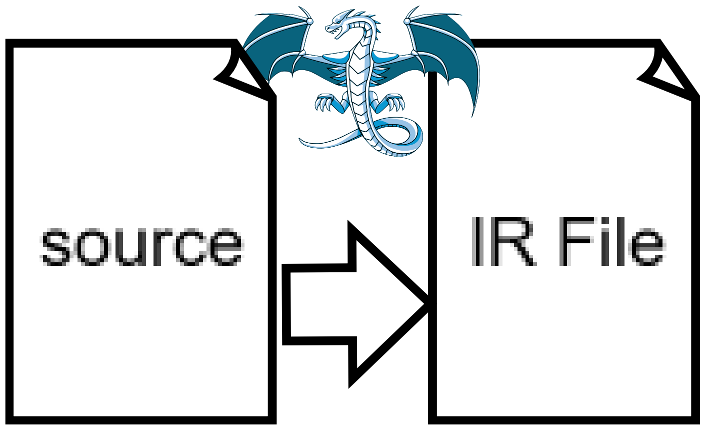
Drawbacks	Prior Works: SimPoint, LoopPoint	Nugget framework
Samples are expensive to find	Rely on tool / simulation to analyze program ✗	Create interval analysis program to **analyze on real hardware** ✓
Samples are tied to a single executable binary	Rely on machine level instruction to define interval ✗	Use **LLVM IR** to define interval ✓
Validating the selected samples is infeasible	Rely on simulation to validate samples ✗	Run samples on real hardware to **validate on real hardware** ✓

The Nugget Framework Pipeline

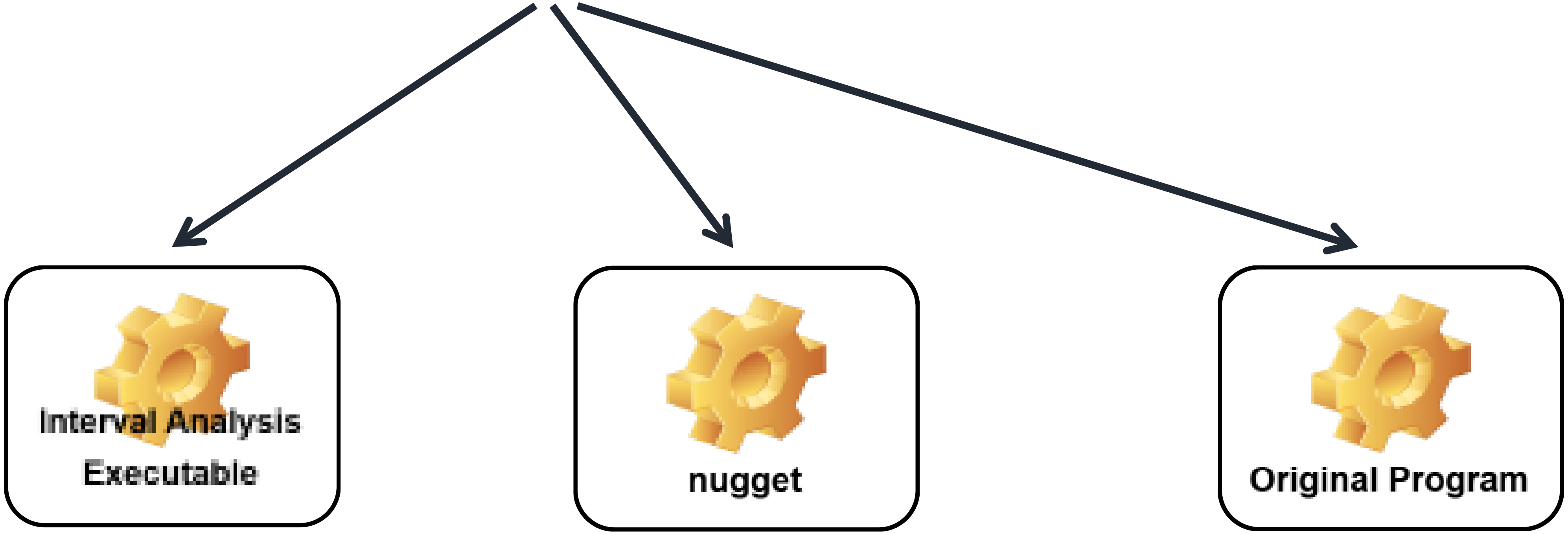


1. Preparation
2. Interval Analysis
3. Nugget Creation
4. Sample Validation

Preparation

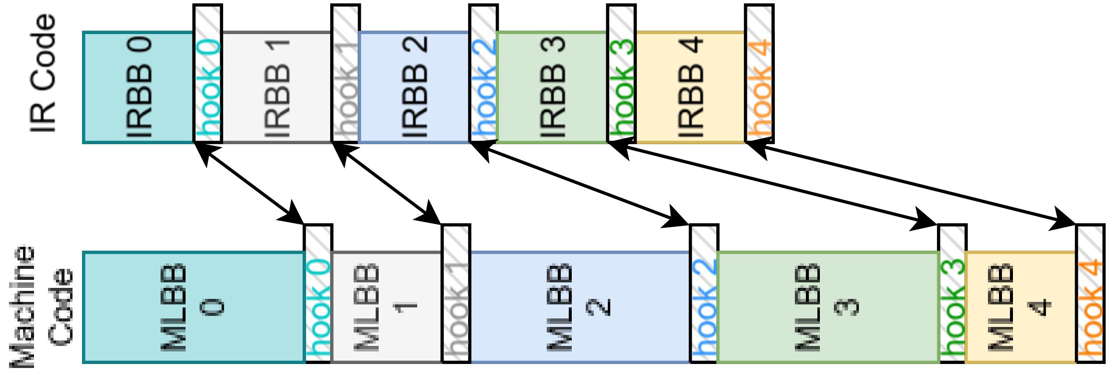


- **One base IR file only**: ensure the IR information is consistent across stages
- **Optimization:** frontend optimization is applied in this step, and backend optimization is applied in different stages.

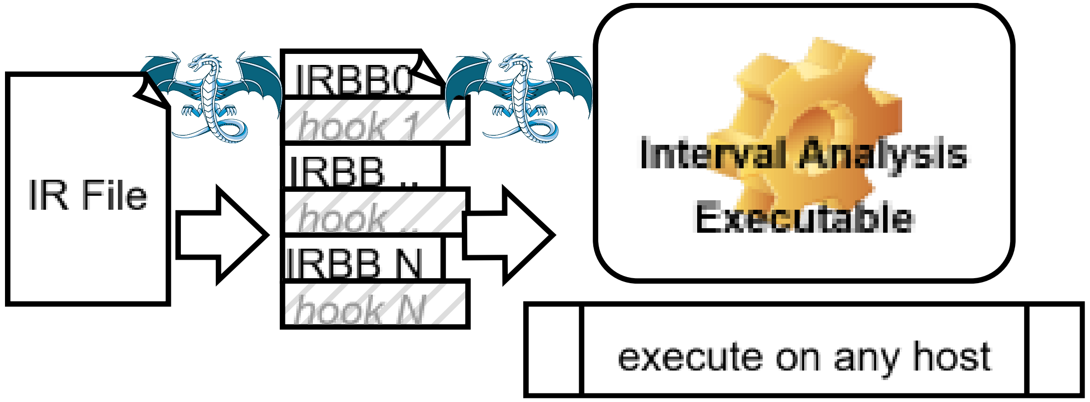


Interval Analysis

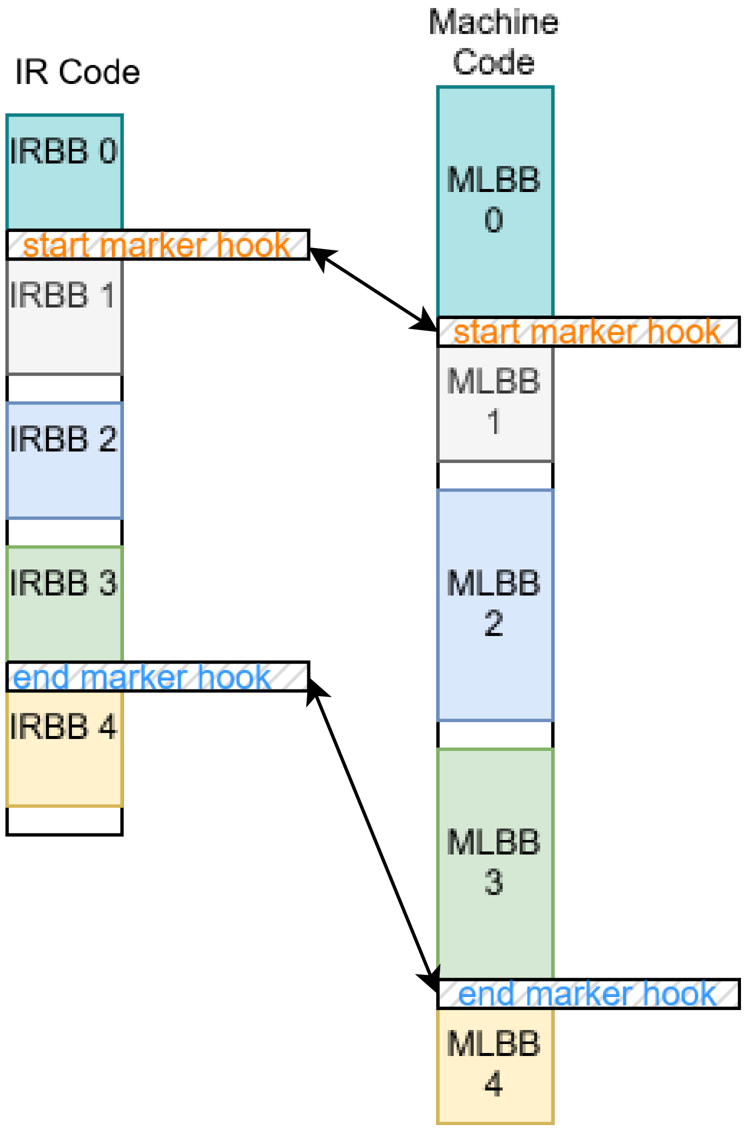
- **Unit of work:** # of IR instruction executed
- **LLVM IR basic block granularity**



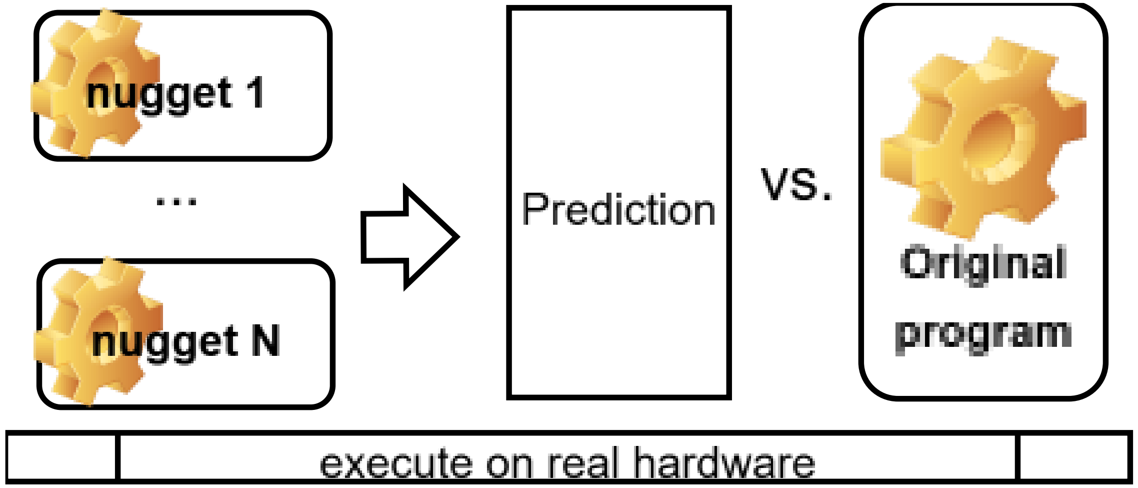

```
hook:
  IR_bbv[IRBB_id] ++;
  IR_inst_counter += IRBB_inst;
  count_stamp_vector[IRBB_id] = IR_inst_counter
  if IR_inst_counter >= interval_length:
    call function();
```



Nugget Creation and Sample Validation



- **Marker:** identifies an execution point
- marker = (IRBB id, execution count)
- Markers bound the sample across platforms



Evaluation Setup

- HW: 24-core Ryzen 3960X (x86) & 160-core Ampere Altra (Arm)
- Simulatior: gem5
- Suites: SPEC2017 (single-thread), NPB (OMP), LSMS (single-thread)
- Inputs: reference for SPEC2017, class A/C/D for NPB, and Fe for LSMS

Evaluation

1. Measure interval analysis overhead
2. Demonstrate portability across architecture (x86, aarch64)
3. Validate sample selection (prediction v.s. measurement)

We also did case studies on

1. Isolate ISA v.s. microarchitecture effects on program behavior by using nuggets in simulation
2. Evaluate simulator fidelity using nuggets (compare to real hardware)

Evaluation

1. Measure interval analysis overhead

578X faster than functional simulation, **3X** for single-thread workloads, and **34X** for multi-thread workloads

2. Demonstrate portability across architecture (x86, aarch64)
3. Validate sample selection (prediction v.s. measurement)

Lower than 10% error in predicting speedup; consistency across machines is a stronger indicator of sample quality than low error on one system

Case studies:

1. Isolate ISA v.s. microarchitecture effects on program behavior by using nuggets in simulation

μarch impacts program behavior more than ISA

2. Evaluate simulator fidelity using nuggets (compare to real hardware)

nuggets can be used as **realistic microbenchmarks**

Conclusion

- Nugget enables fast program execution analysis on real hardware (**578X** faster than using function simulation).
- By using LLVM IR as the unit of work, the analysis is a one-time cost—samples can be reused across different architectures.
- Selected samples can be validated quickly for the target benchmark and input size.
- Overall, Nugget increases confidence in the prediction/estimation results.
- GitHub repo: studyztp/Nugget-LLVM-passes

Nugget is only a start

1. What new sampling methodologies can be created using Nugget? What LLVM IR information that can represent hardware performance phases?
2. Can recrate the start of the sample?
3. …