Design space-aware statistical simulation with machine learning

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10/7/2021

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Introduction

- Design space exploration: How to evaluate the performance of an application on many architecture configurations?
  - Use simpler surrogate applications
  - Use statistical simulation?
- Some of program intervals may not be sensitive to the architecture changes, and re-running them on each architecture may be wasteful
- Identify important program intervals for performance modeling
- Learn a mapping from interval performance to application performance

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Statistical simulation

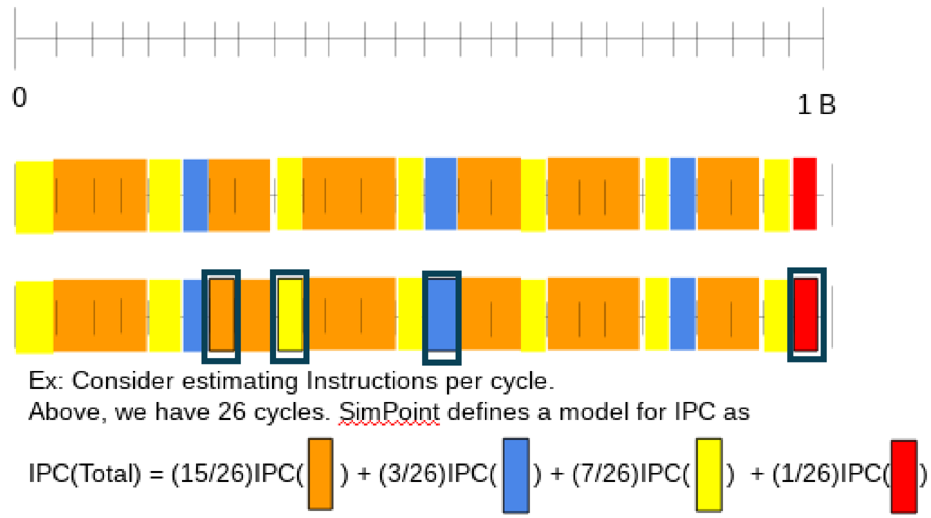
Statistical simulation speeds up simulation by only performing detailed simulation on small portions of a program and extrapolating the results for a whole-program estimate (1-2)

SimPoint divides a program into intervals and groups intervals together based on their behavior similarity

- Measured with basic block features (that is, if two intervals involve execution of many of the same basic blocks then they are similar)

Detailed simulation is performed on a representative interval of each cluster, and fast forwarding is used between these intervals.

Combine measurements on representative intervals to get whole program estimate



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2. Hamerly, G., Perelman, E., Lau, J., & Calder, B. SimPoint 3.0: Faster and More Flexible Program Phase Analysis. *J. Instr. Level Parallelism, 7*. (2005).

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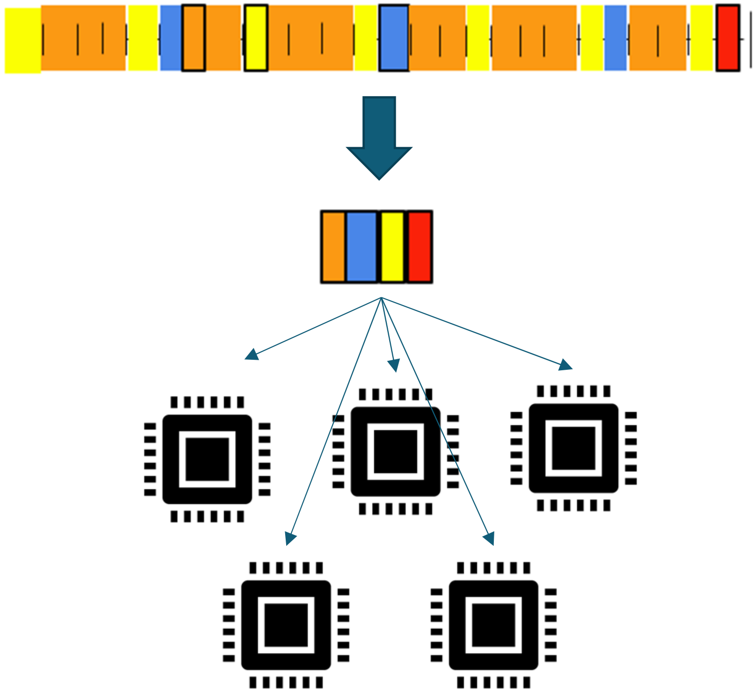
Design space exploration



- A typical application of statistical simulation would be to estimate program performance over many configurations
- For each configuration, run the small number of intervals, and use a weighted sum to estimate performance
- However, this may cause some difficulties:
  - Since the intervals in a cluster are only similar, and not equal, it's not clear that a simple weighted sum is the most accurate model
  - Some intervals may not be sensitive to the design space variables

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Design-space aware statistical simulation

- Run SimPoint to obtain a set of phases
- Correlate phase performance profiles with design parameters
- Toss out uncorrelated phases
- Among "interesting" phases, build a model of phase → application performance

- Run SimPoint to obtain a set of **n** phases and representative intervals $\mathbf{p_1, \ldots, p_n}$.
- Choose **m** design settings $\mathbf{v_1, \ldots, v_m}$ (a small portion of overall space)
- Obtain performance **r** of the **n** intervals on each of **m** configurations.
  - Evaluate $\mathbf{r(i, v_k)}$ for **i=1…n** and **k=1…m**
- For each interval, find correlation **c(i)** between $\mathbf{[\ r(i, v_1), r(i, v_2), \ldots, r(i, v_m)\ ]}$ and $\mathbf{[\ v_1, v_2, \ldots, v_m\ ]}$
- Keep the top **k** intervals in terms of correlation, discarding the rest.
  - Represented by k indices $\mathbf{g_1, g_2, \ldots, g_k}$
- Run the application **q** at the **m** configurations, obtaining performance measurements $\mathbf{r(q, v_1), r(q,v_2), \ldots, r(q,v_m)}$
- Learn a mapping $\mathbf{f : R^k \rightarrow R}$ from the interval performances to application performances (e.g. using ML)
  - **for j=1…m** , $\mathbf{f(\ r(g_1, v_j), r(g_2,v_j), \ldots , r(g_k, v_j)\ ) = r(q,v_j)}$
- Prediction: Given a new configuration **v**, run the top **k** intervals to get performance result, then plug into ML model.
  - Evaluate $\mathbf{r(g_1,v), r(g_2,v), \ldots r(g_k,v)}$
  - Estimate runtime as $\mathbf{r(q,v) \sim f(r(g_1,v), r(g_2,v), \ldots r(g_k,v))}$

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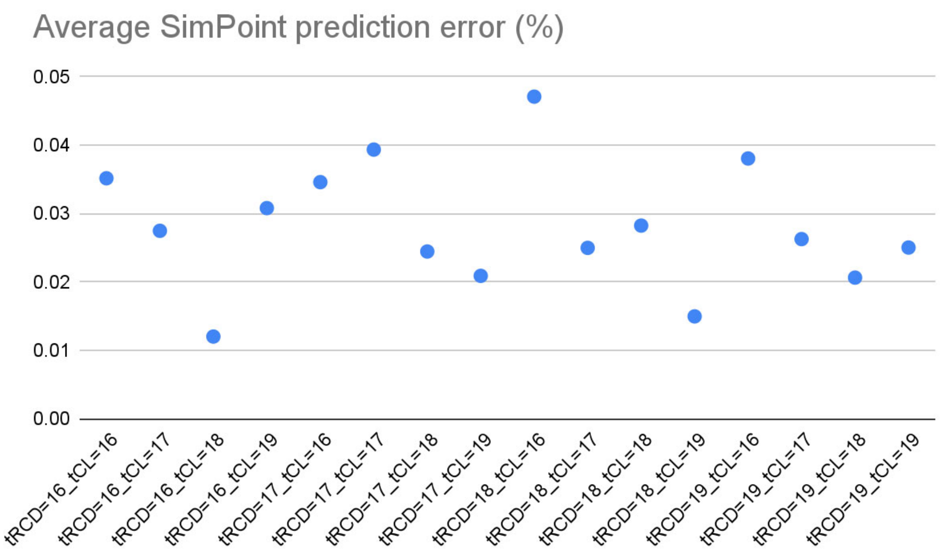
Application to the SPEC benchmarks

Evaluation of our methodology to predict CPI in SPEC programs

- Evaluated ground truth of benchmark runtimes.
- Apply SimPoint to get a baseline prediction estimate
- Next steps are to apply DSA-SimPoint, and compare results.
- Later, consider DL-based clustering approaches, based on SimNet



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