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Partitioning Streaming Parallelism for Multi-cores: A Machine Learning Based Approach

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PACT
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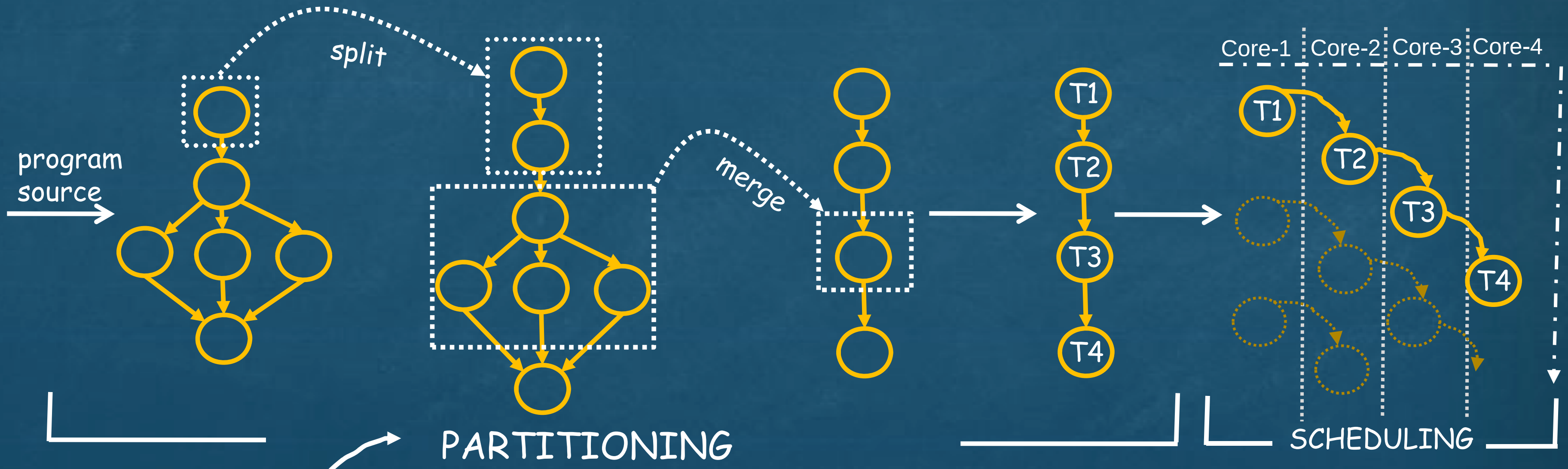
Background

- Applications:
  - Stream programs written by high level programming languages
- The problem:
  - Partitioning streaming applications for multi-cores



* We focus only on the partitioning stage in this work!

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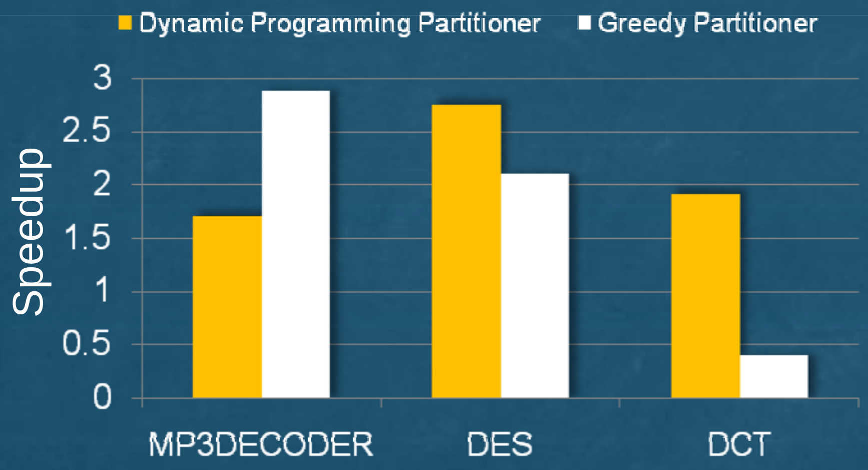
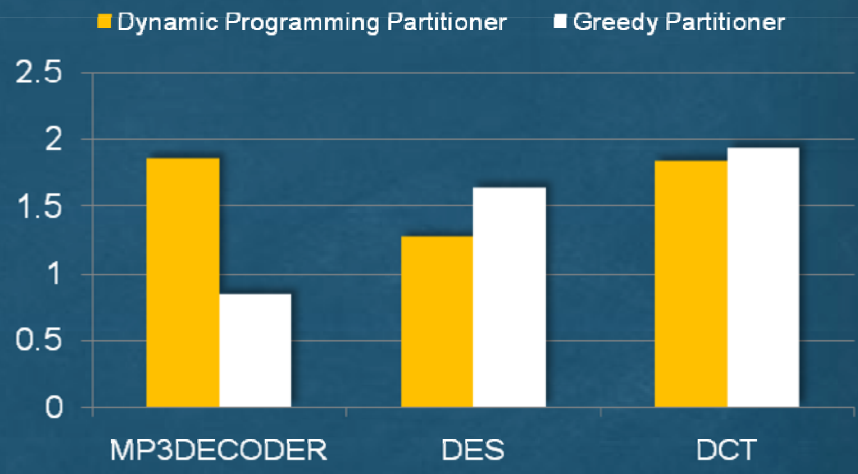
Why not Partitioning Heuristics?

- Hardwired heuristics might not adapt to different platforms

*Baseline is a naïve graph partitioner.



(a) **Intel Xeon 4-core (2x dual-cores)**



(b) **Intel Xeon 8-core (2x quad-cores)**

* The best partitioning strategy varies across programs and platforms.

Why Machine Learning?

- It can automatically learn from data; then, reuses the learned knowledge

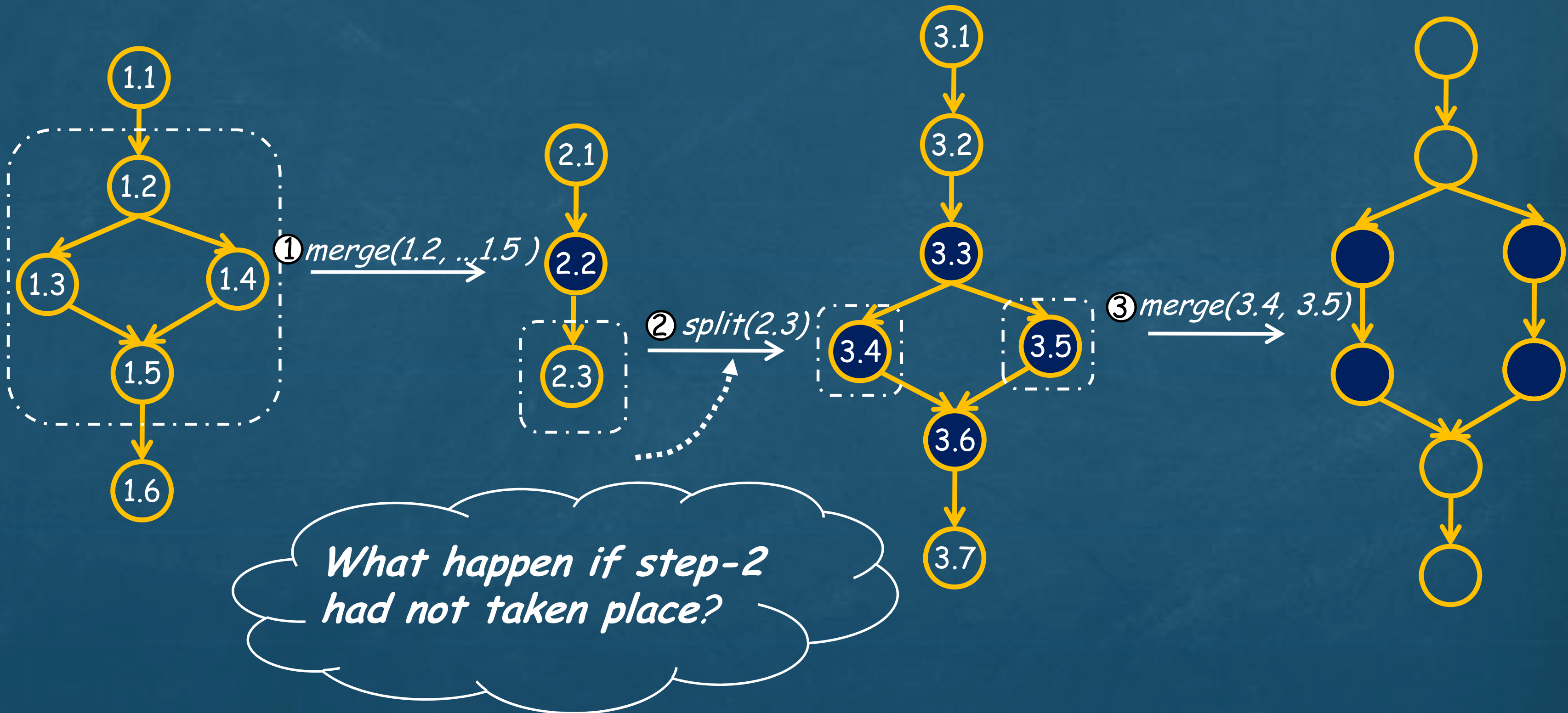
- Advantages:
  - Doesn't require expert knowledge and is portable across platforms
- We use supervised learning technique in this work
  - **Classical** supervised learning directly predicts the partitioning sequence

This is a Different Machine Learning Problem

- Previous machine learning based work limits on ***fixed*** targets
  - Determining the compiler flag settings
    - (Cavazos et al., CGO'07; Hoste and Eeckhout, CGO'08; Dubach et. al, MICRO'09)
  - Determining loop unroll factors
    - (Mark and Saman, CGO'05)
  - #Threads per parallel loop
    - (Wang and O'Boyle, PPoPP'09)
- We are dealing with a problem with ***unbounded*** graph structure
  - The graph structure changes after each operation

The Challenge

- The partitioning sequence is ***unbound*** and the graph ***changes*** after every operation.



* It is difficult for a predictive model to make sure each intermediate stage is 100% correct!

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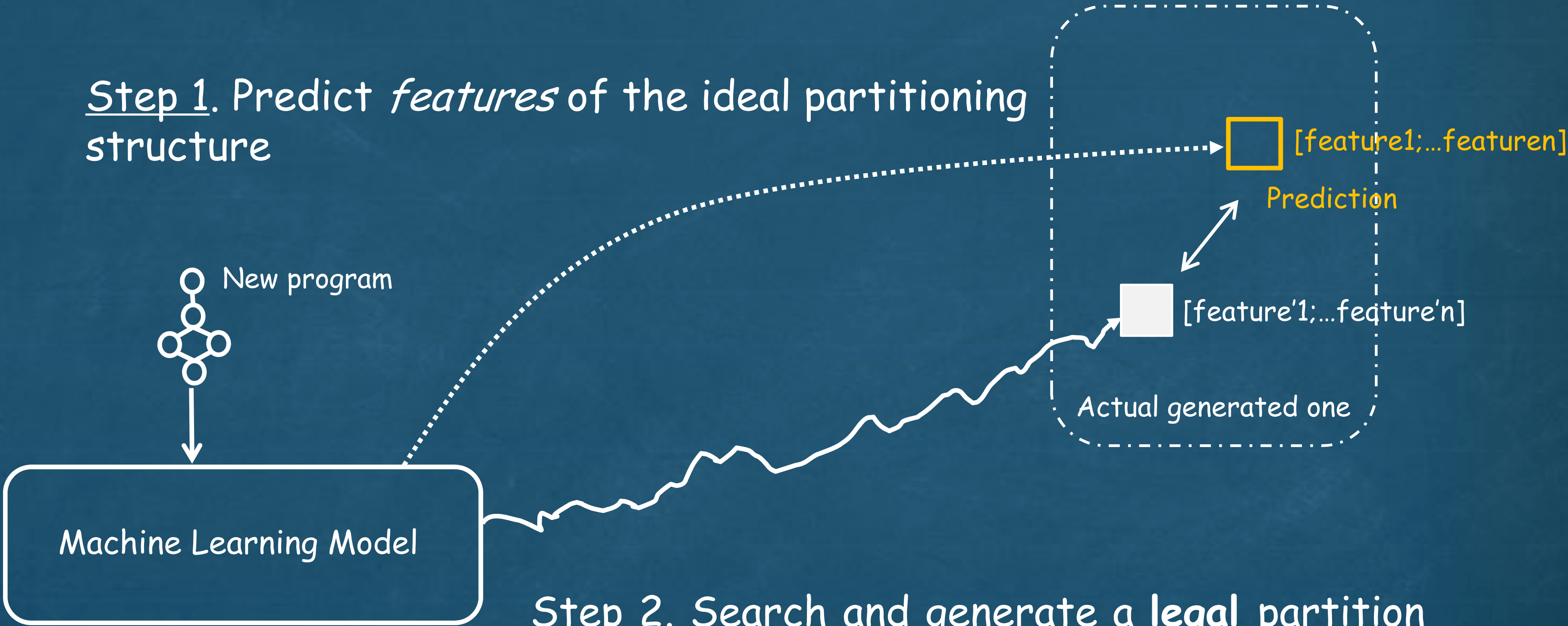
Our Two-Step Approach

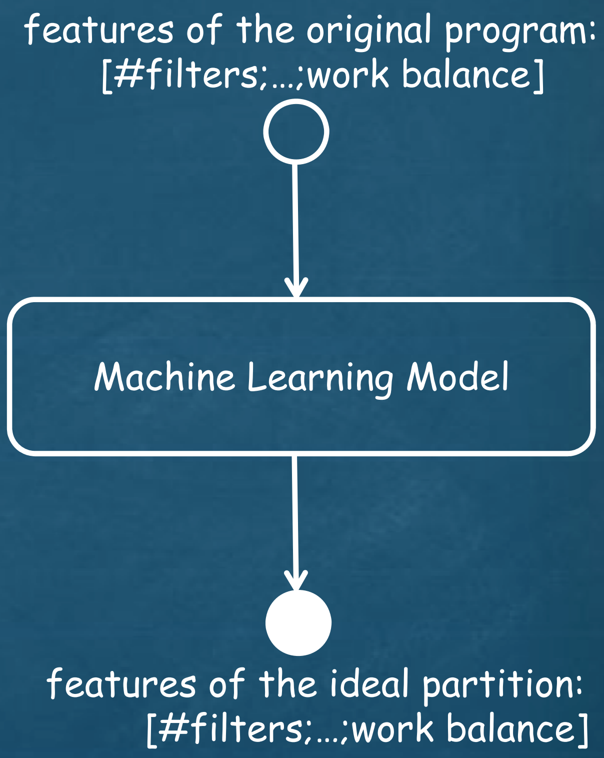
Step 1. Predict *features* of the ideal partitioning structure



Step 2. Search and generate a **legal** partition as closed to the features of the predicted structure as possible.

Using Program Features to Characterise the Original Program and a Partition

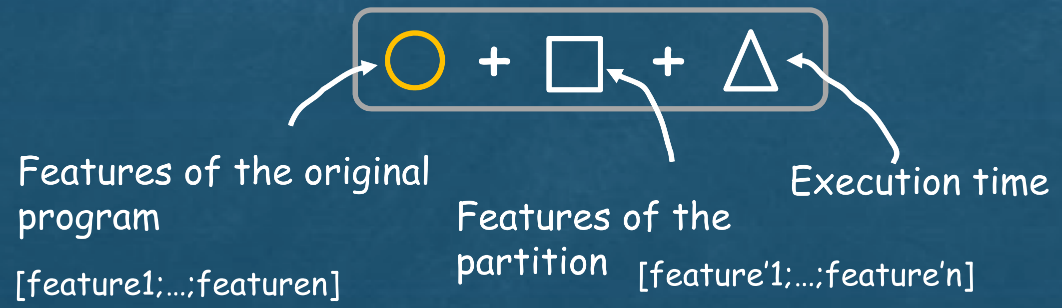
Static program features	
#Filters	#Joiners
Pipeline depth	Splitjoin width
Avg. unit work	Max unit work
Pipeline work	Splitjoin work
Computation	Computation of stateful filters
Branches per inst	Load/Store per inst
Avg. communication rate	Computation-communication ratio
Avg. commun. / unit work	Avg. bytes commun. / unit work
Max commun. /unit work	Work balance



Generate Training Data

- Using features to characterise both the program and generated partitions
  - Training is performed off-line using a set of training programs.

A training example:



*The key point is to summarise features of the ideal partitioning structure.

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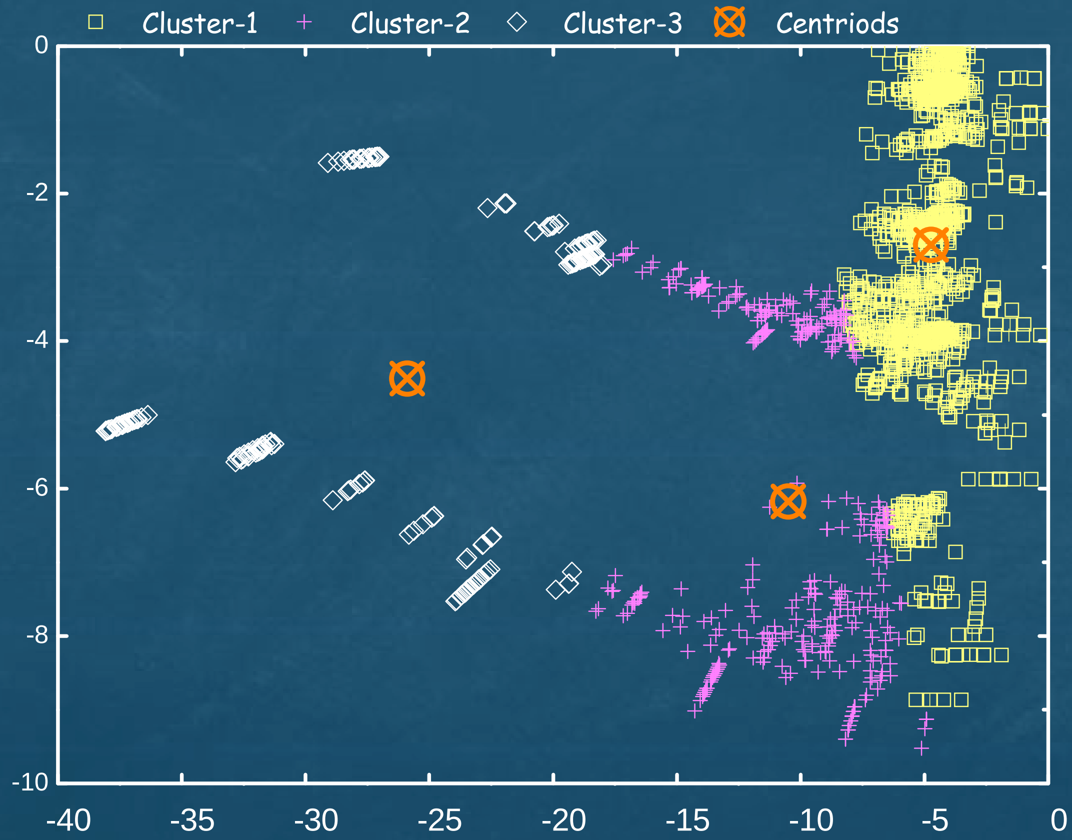
Summarise the Ideal Partitioning Structure (Training)

- Using K-Means clustering algorithm to summarise the best partition of a program



* The multi-dimensional feature space has been projected to a two-dimensional one.

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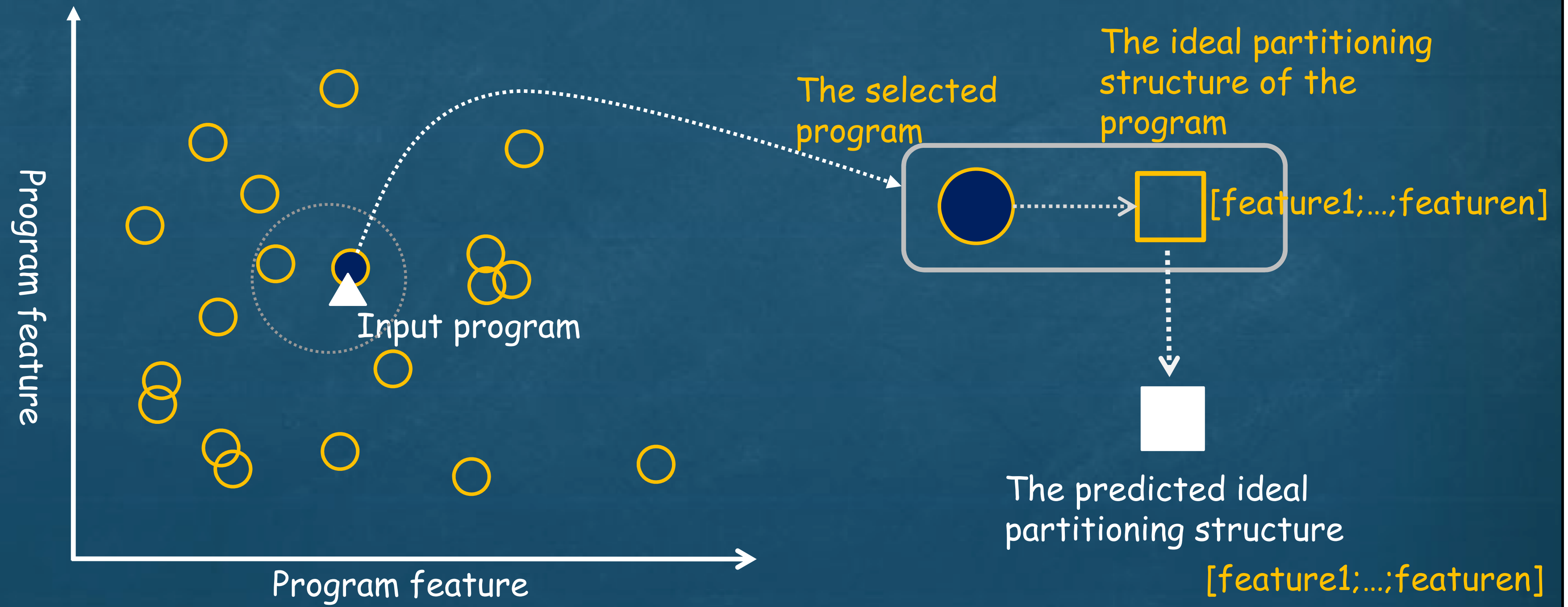
Train and Use the Model

- Nearest-Neighbour Algorithm
  - Pick a program from the training set, whose features most closely match the input program's features



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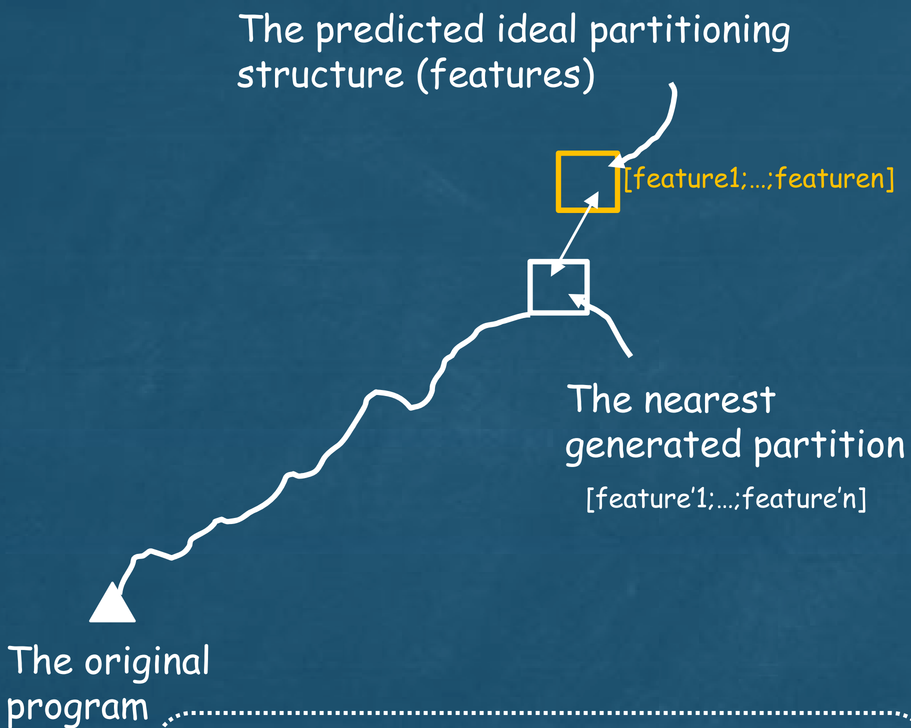
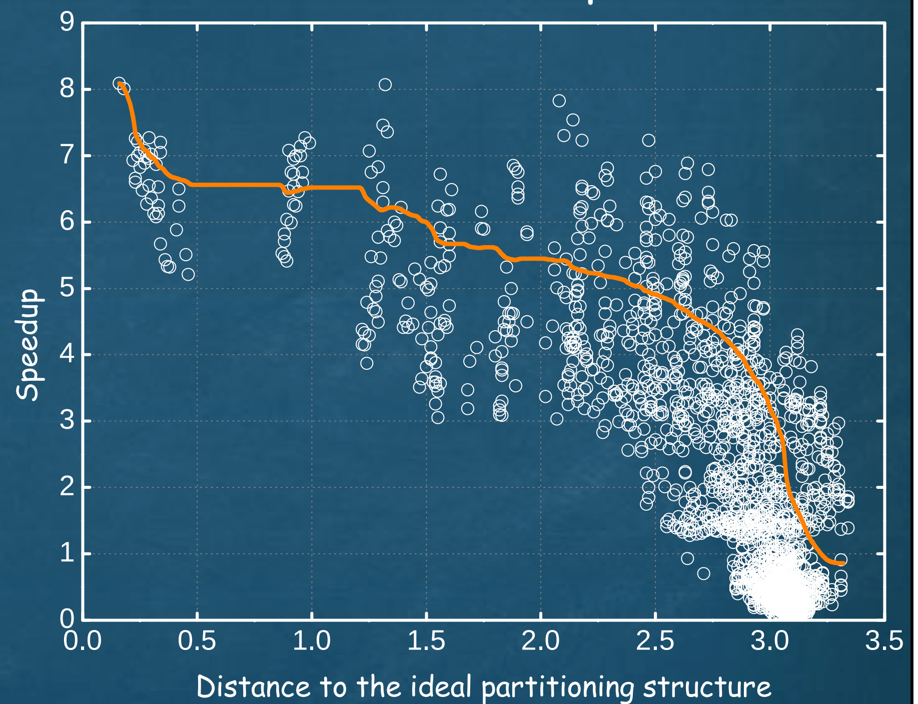
Searching and Generating a Legal Partition



Randomly generate partitions and select the partition nearest the predicted ideal structure.

A search example



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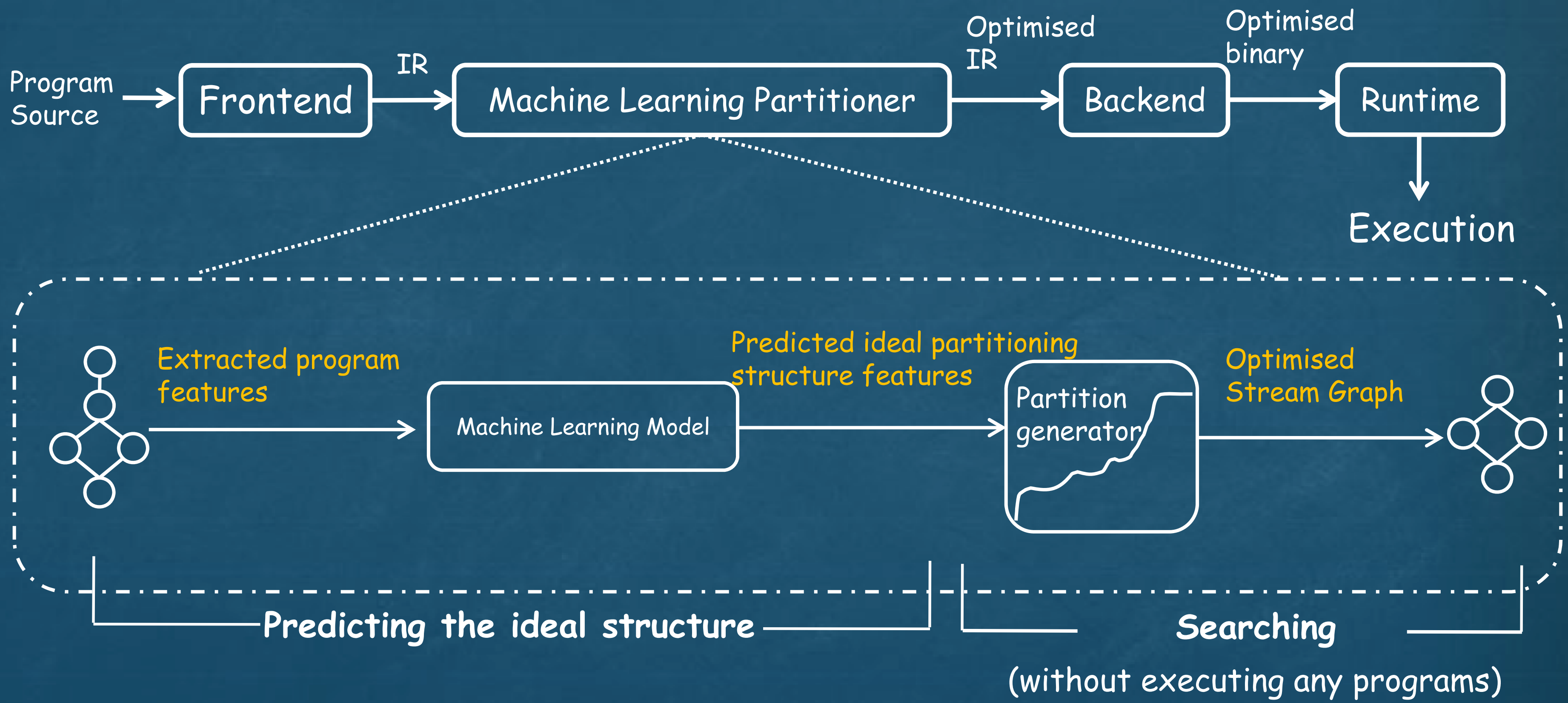
The Compilation Framework



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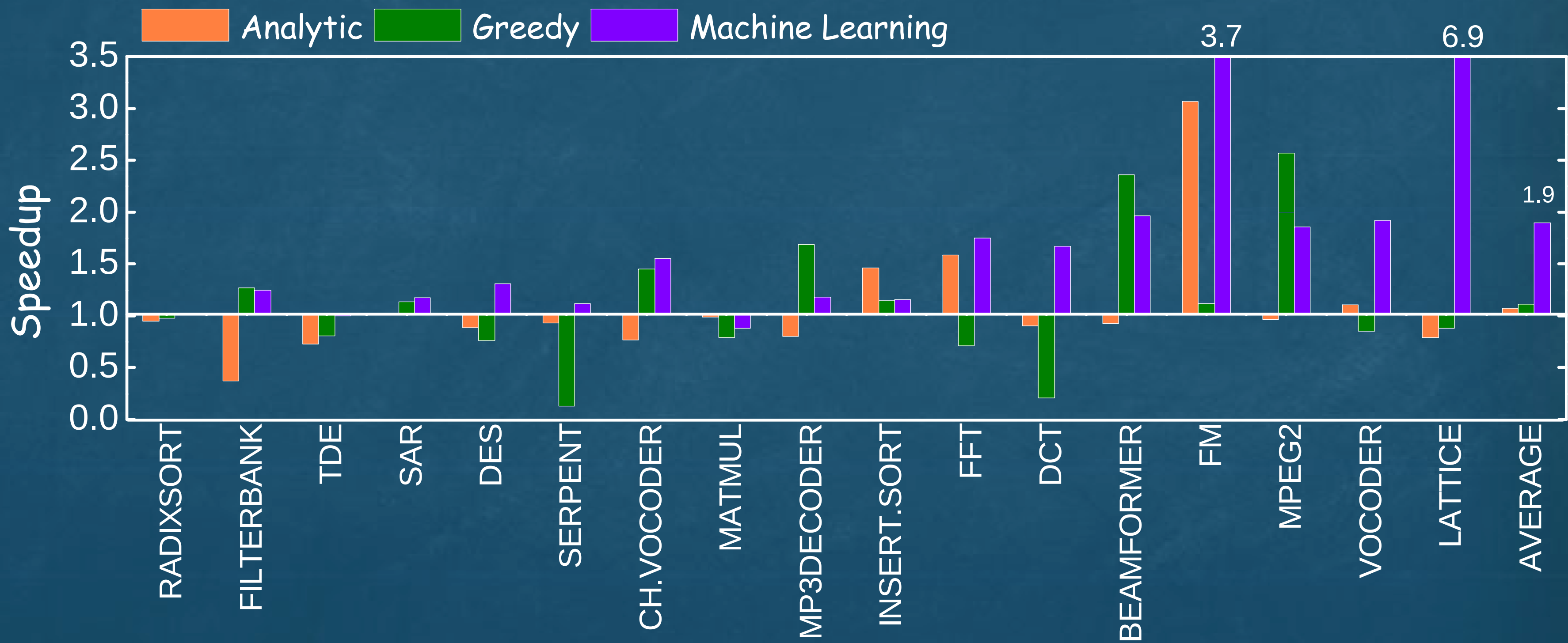
Experimental Setup

- Platforms
  - 2 x Dual Intel Xeon 5160 processors (4 cores in total)
  - 2 x Quad Intel Xeon 5450 processors (8 cores in total)
- Compilers:
  - StreamIt version 2.1.1
  - Intel ICC v11.0
    - -O3 -xT -aXT –ipo
- Benchmarks:
  - 17 StreamIt applications
- Comparison:
  - 2 StreamIt compiler built-in partitioners
  - An analytical-based model (*Navarro et al., PACT 2009*)
- Evaluation Methodology:
  - Leave-one-out-cross-validation
    - Making sure the model has NOT seen the target program before.
  - Baseline: StreamIt dynamic programming-based partitioner

Results on the Intel 4-Core Platform (1.9x)

- Our approach achieves **1.9x** speedup over the StreamIt default scheme

*Baseline: StreamIt dynamic-programming-based partitioner



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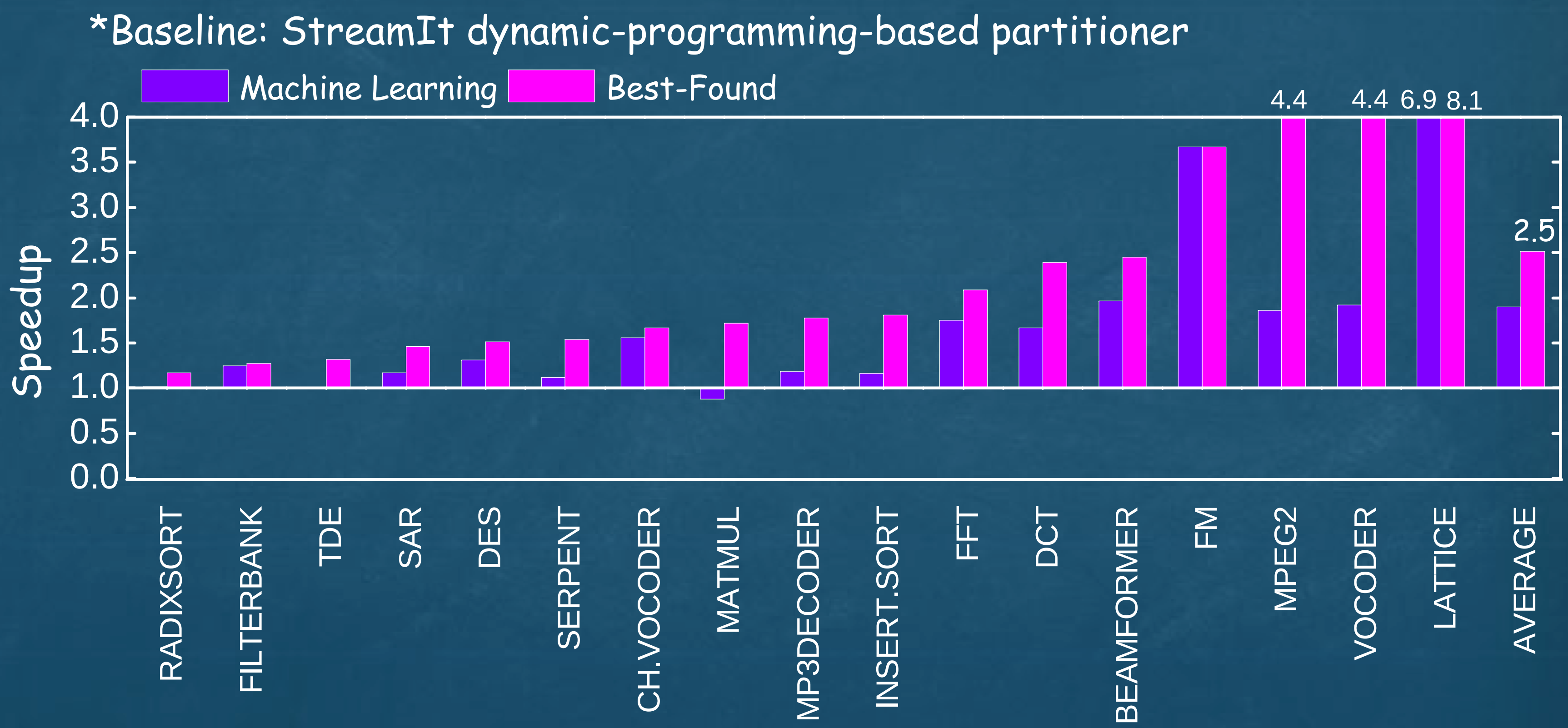
Machine Learning vs. Best-Found (Intel 4-Core)

- Our approach achieves 60% of the Best-Found performance



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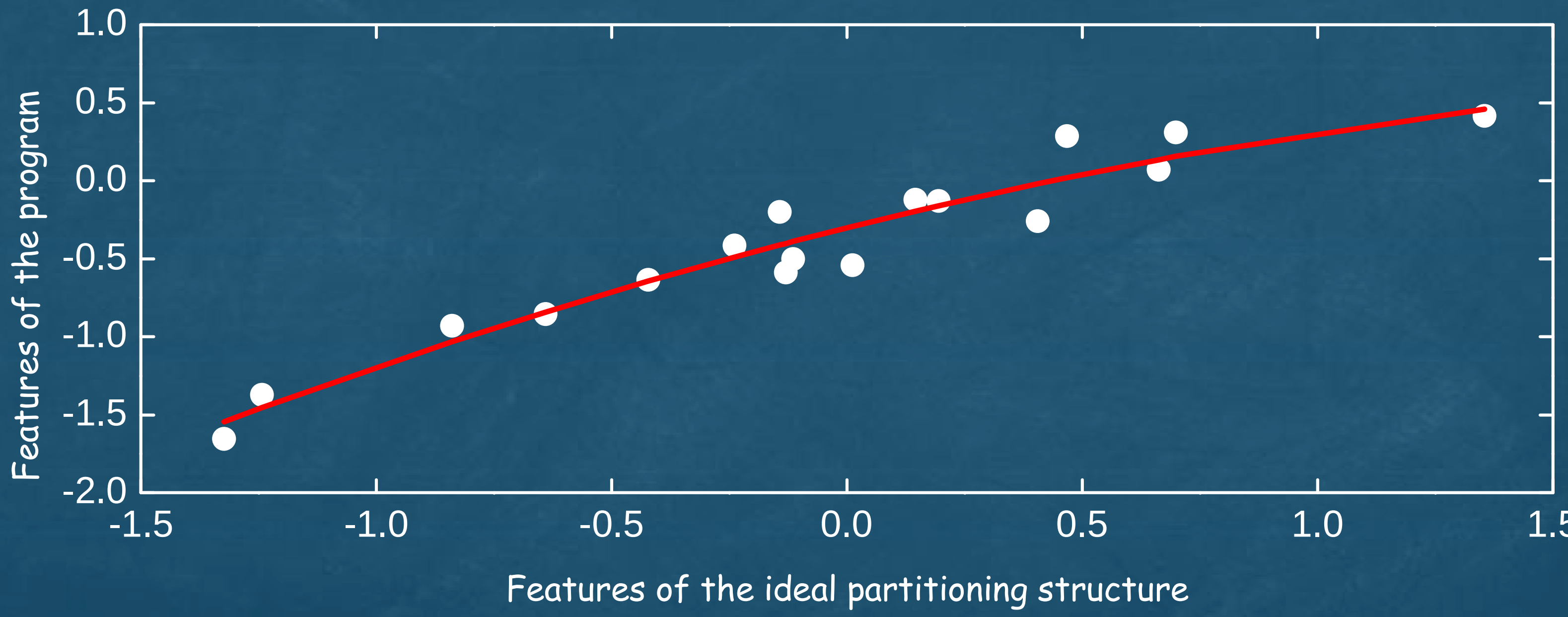
Similar Programs Have Similar Ideal Partitioning Structures

- Correlation of programs and the ideal partitioning structures



*The original multi-dimensional feature space have been projected into a single value.

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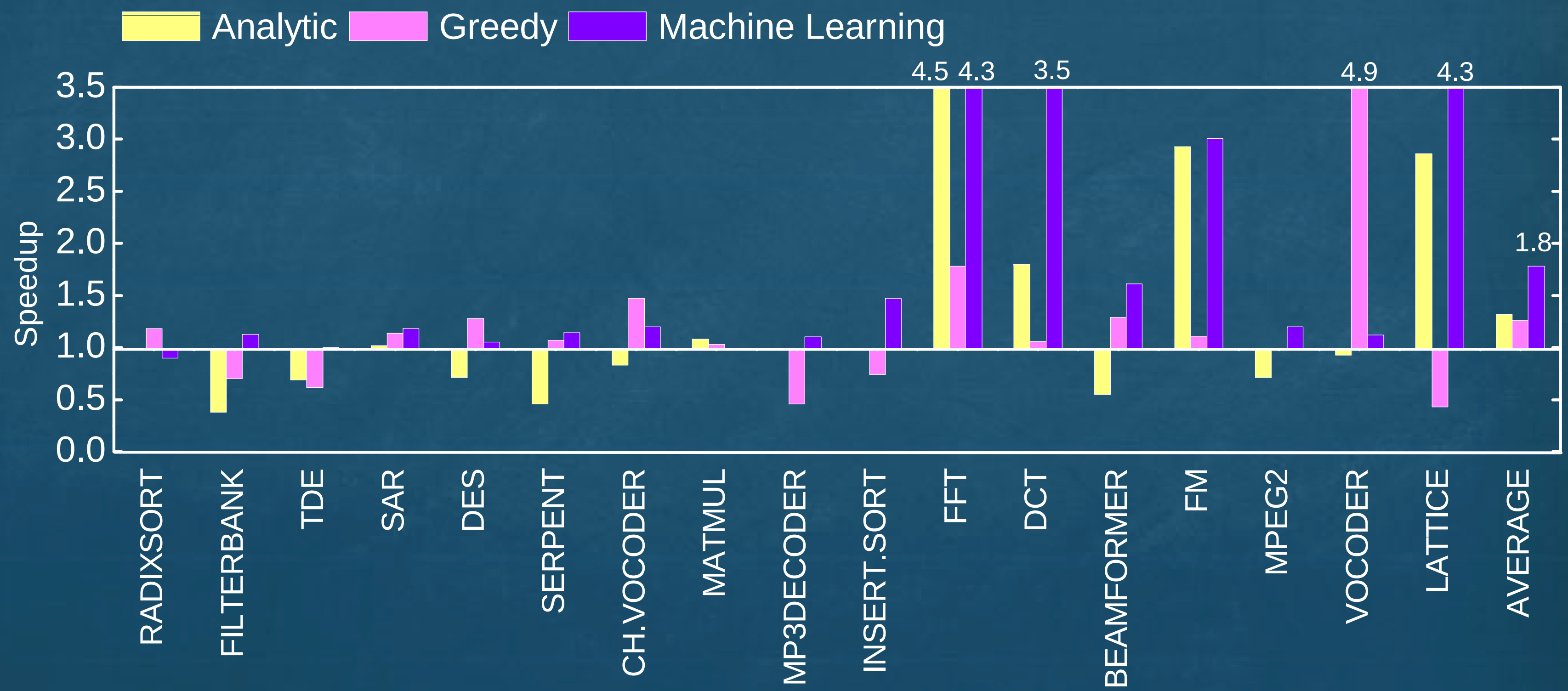
Adapt to the Intel 8-core Platform (1.8x)

- Our approach achieves1.8x speedup over the StreamIt default scheme

*Baseline: StreamIt dynamic-programming-based partitioner



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Conclusions

- A machine learning based approach for partitioning streaming applications
  - The model is firstly trained *off-line*
  - Predicting the ideal partitioning structure used the trained model
  - Searching a legal partition closest to the predicted structure (without running any code)
- Comparison with heuristics and analytical-based approaches
  - Better performance and more stable across programs and platforms
  - An automatic and portable scheme

Thank You

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