THE UNIVERSITY *of* EDINBURGH
informatics

icsa
Institute for Computing
Systems Architecture

PPar Lunch 2014/12/10

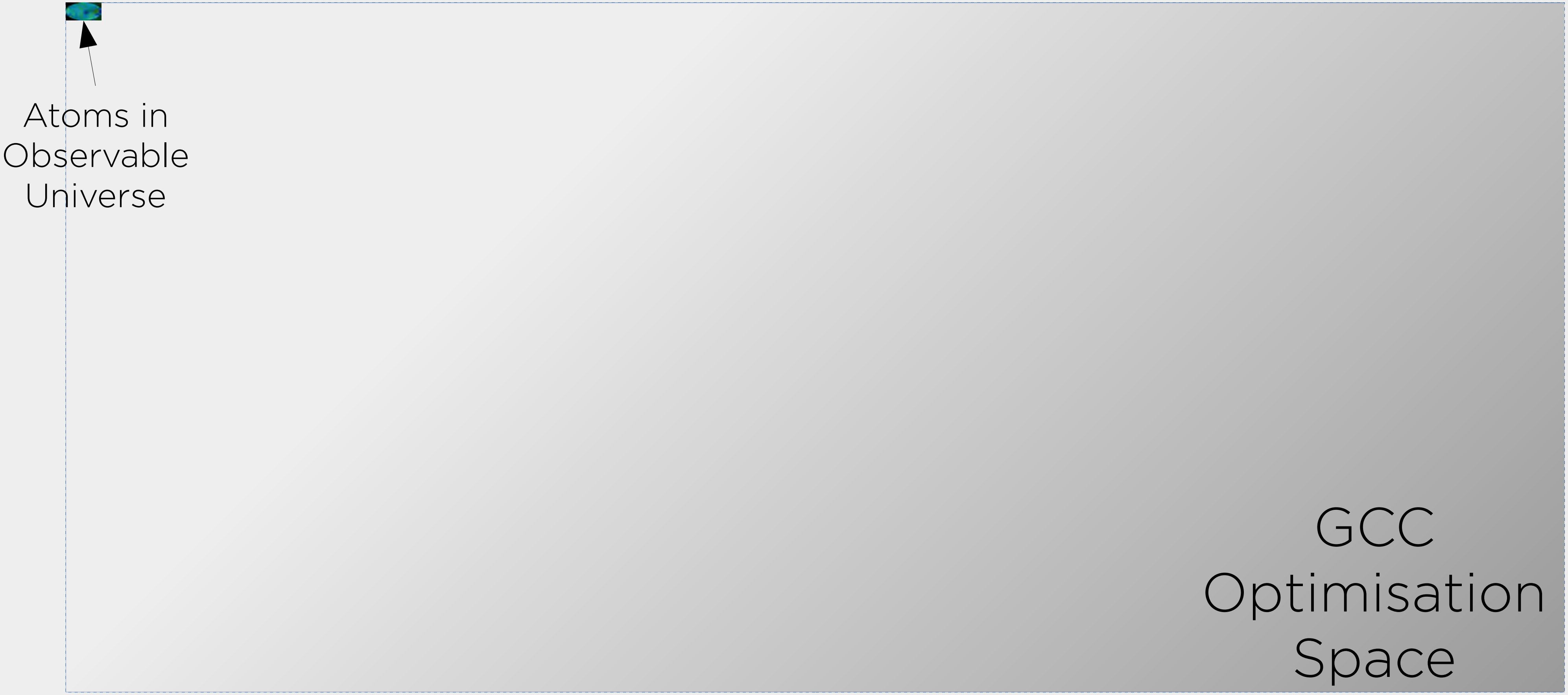
Iterative Compilation 1.01

Compiler optimisations

- Modern Compilers:
  - 100s of possible code transformations
- GCC 4.8.1:
  - 205 optimisation options
  - 138 parameters affecting optimisation

Compiler optimisations

- ~10^{340} combinations!
- ~10^{82} atoms in the universe



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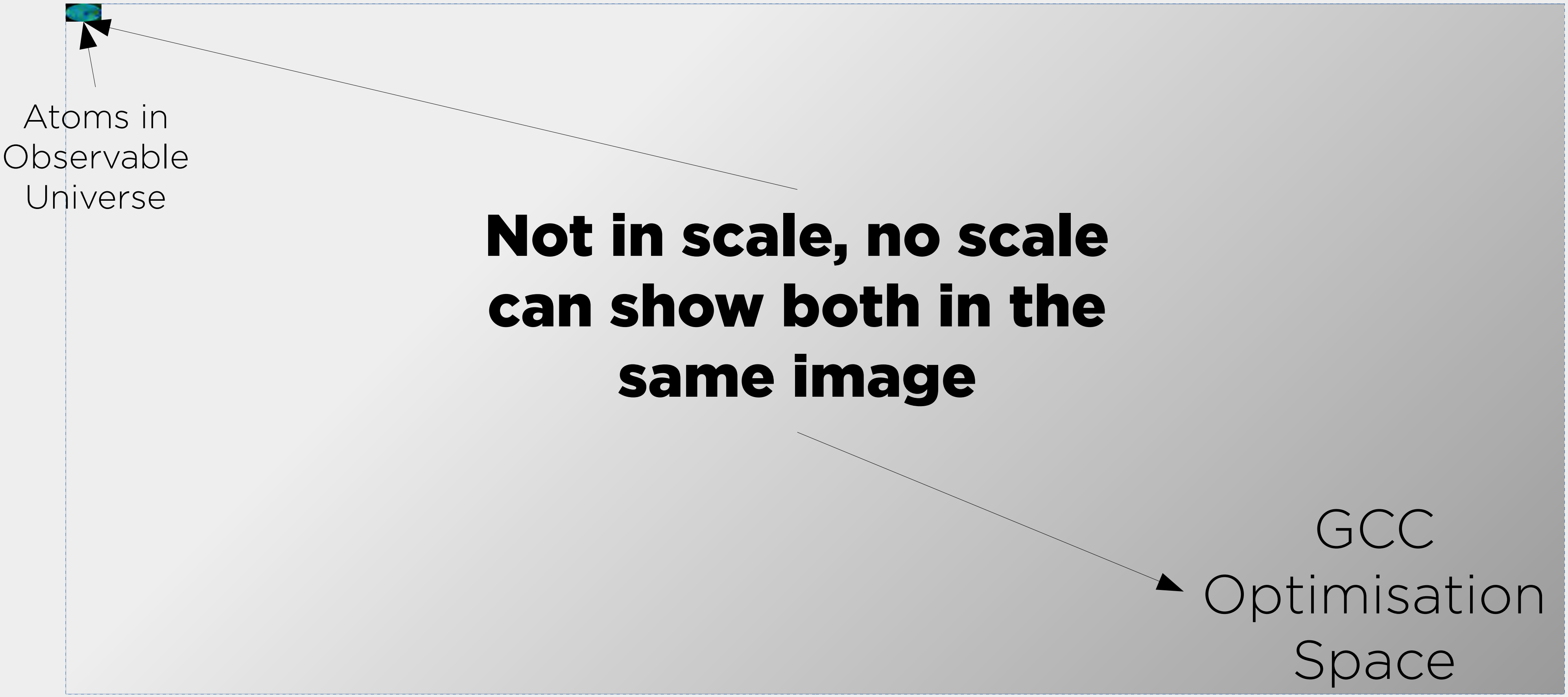


Atoms in Observable Universe

Not in scale, no scale can show both in the same image

GCC Optimisation Space

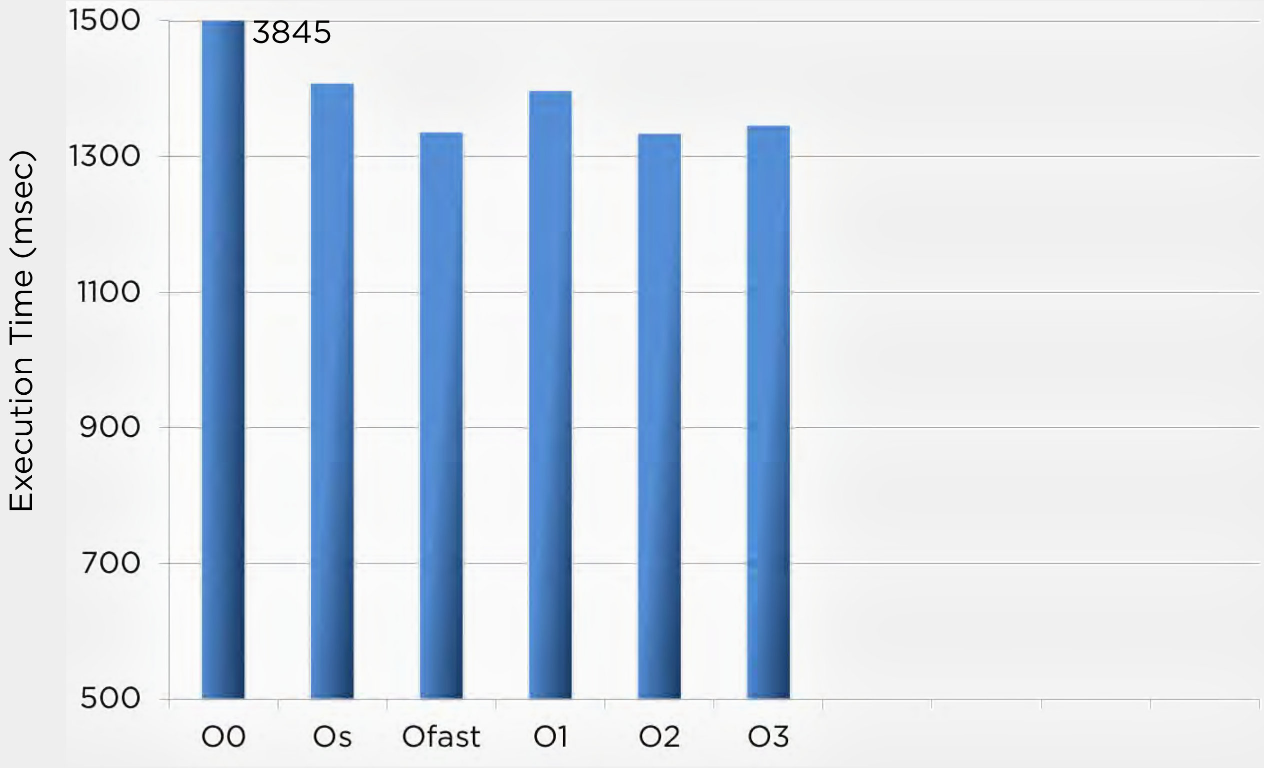
How do we choose optimisations?

How do we choose optimisations?

- Try each one on its own
  - Transformations affect each other
- Use an expert to find the best combo
  - Experts are few
  - One optimisation set doesn't fit all
- Use analytical models
  - Could help, but far from perfect
  - Architecture dependent

Choosing options - Example

- Usual approach: Let's pretend -O2 is the optimal choice
  - Enables transformations which usually improve performance
  - But not the optimal set of transformations for each program
- libquantum benchmark:



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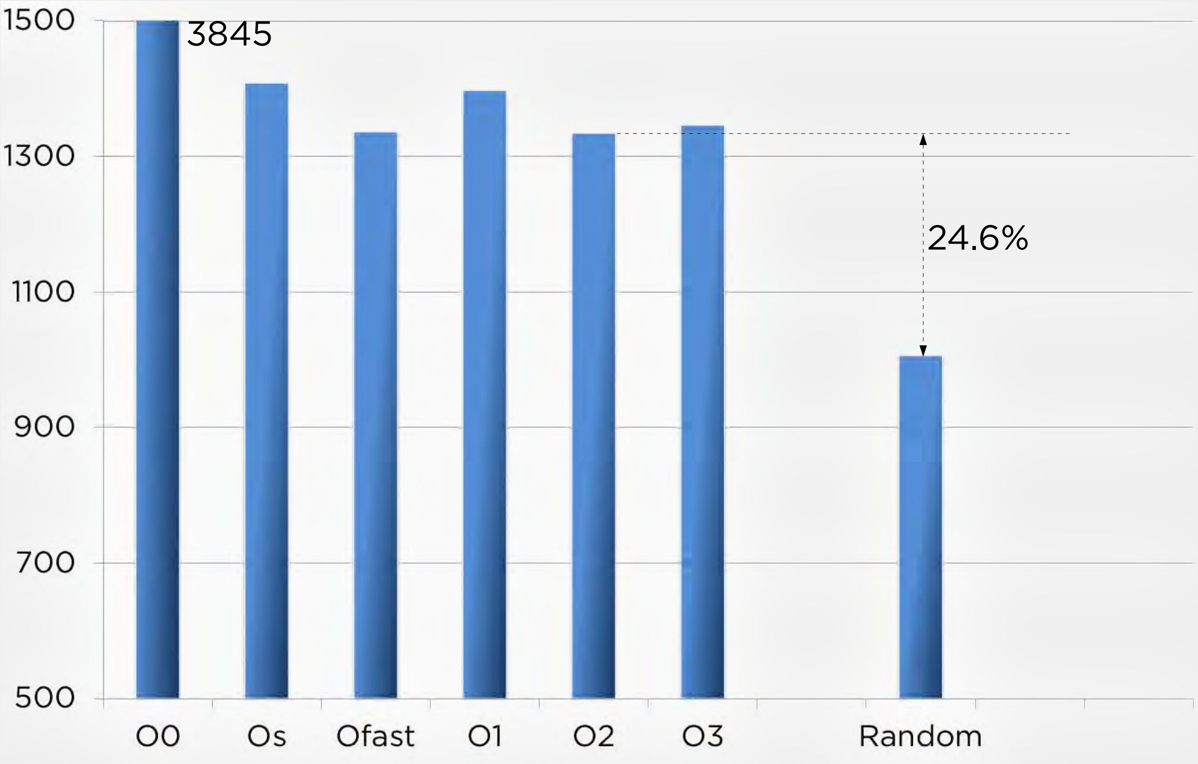
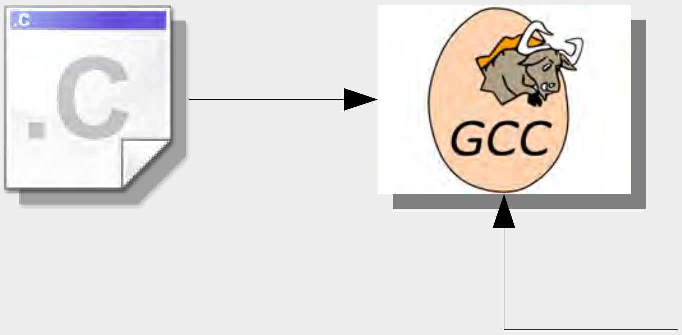


Choosing options

- Performance is lost because of inefficient optimisation strategies
- How do we harvest all the potential performance?

Iterative compilation

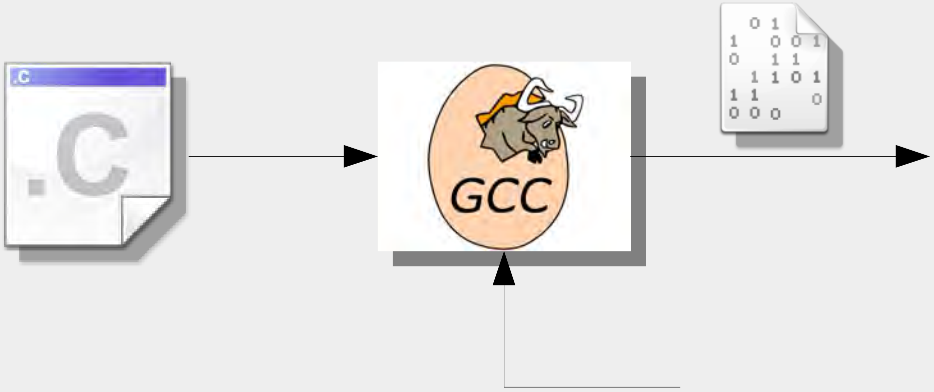
- Choose options



Options

Iterative compilation

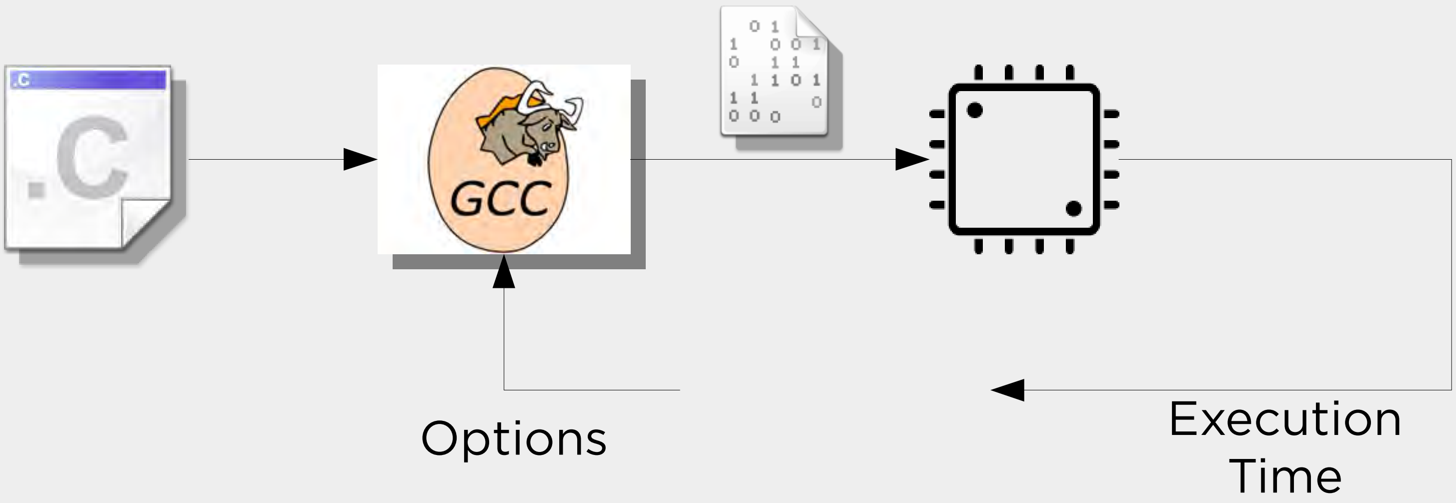
- Choose options
- Build the executables



Options

Iterative compilation

- Choose options
- Build the executables
- Get their runtime

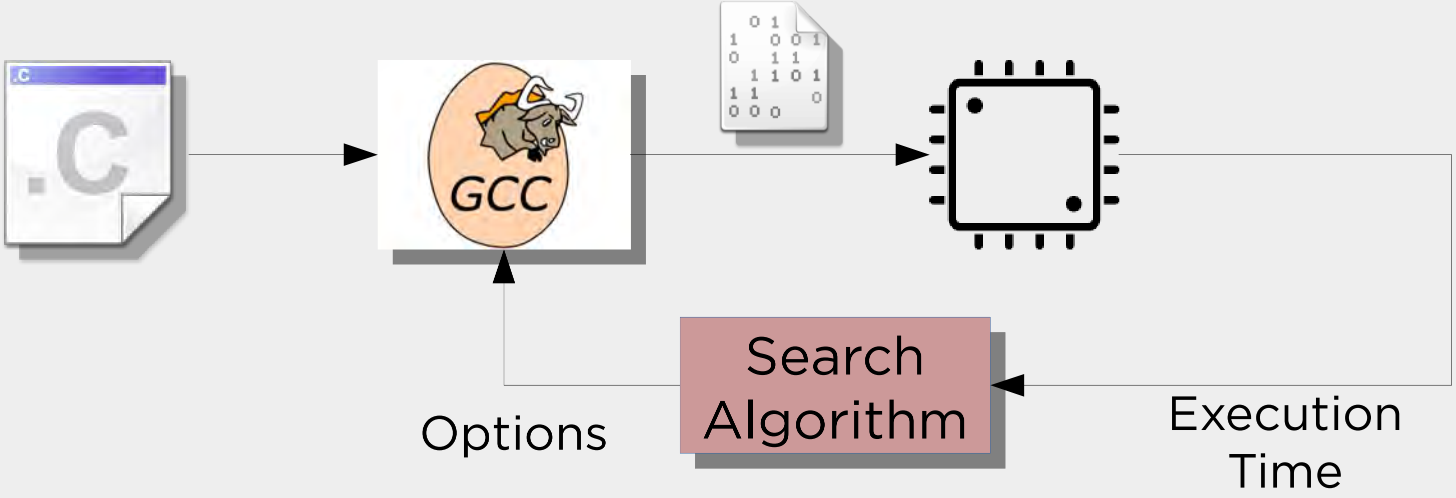


Options

Execution Time

Iterative compilation

- Choose options
- Build the executables
- Get their runtime
- Based on the results, choose the next round of optimisation options and repeat



Search Algorithm

Options

Execution Time

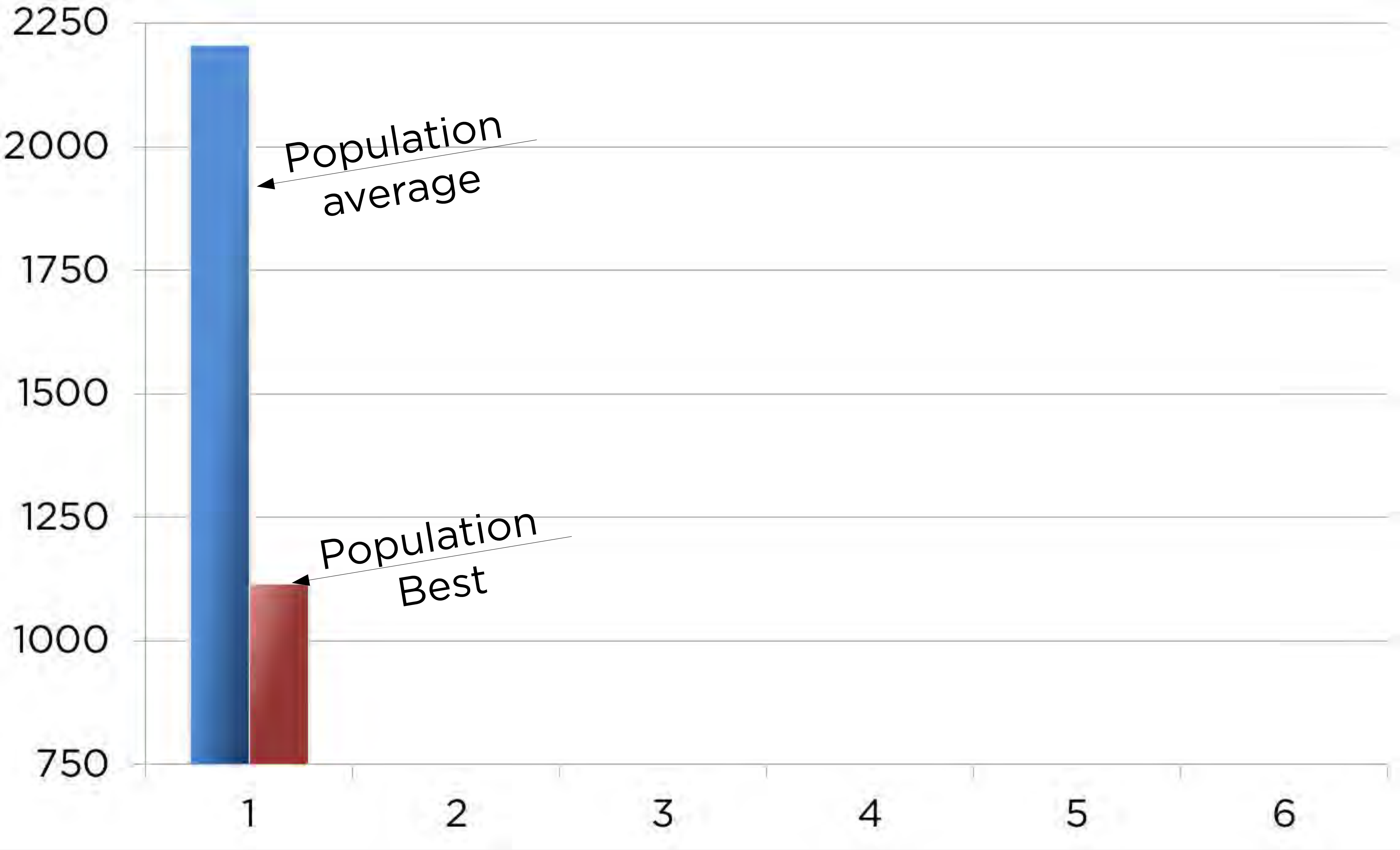
Search Algorithms

- Search algorithm choice → critical parameter
  - Genetic Algorithm, Simulated Annealing, Grid Search, Window Search, etc.
- General Idea:
  - Find high performing areas of the space
  - Improve your knowledge of these areas

Iterative compilation - Example

- libquantum + Genetic Algorithm

Iterative compilation - Example



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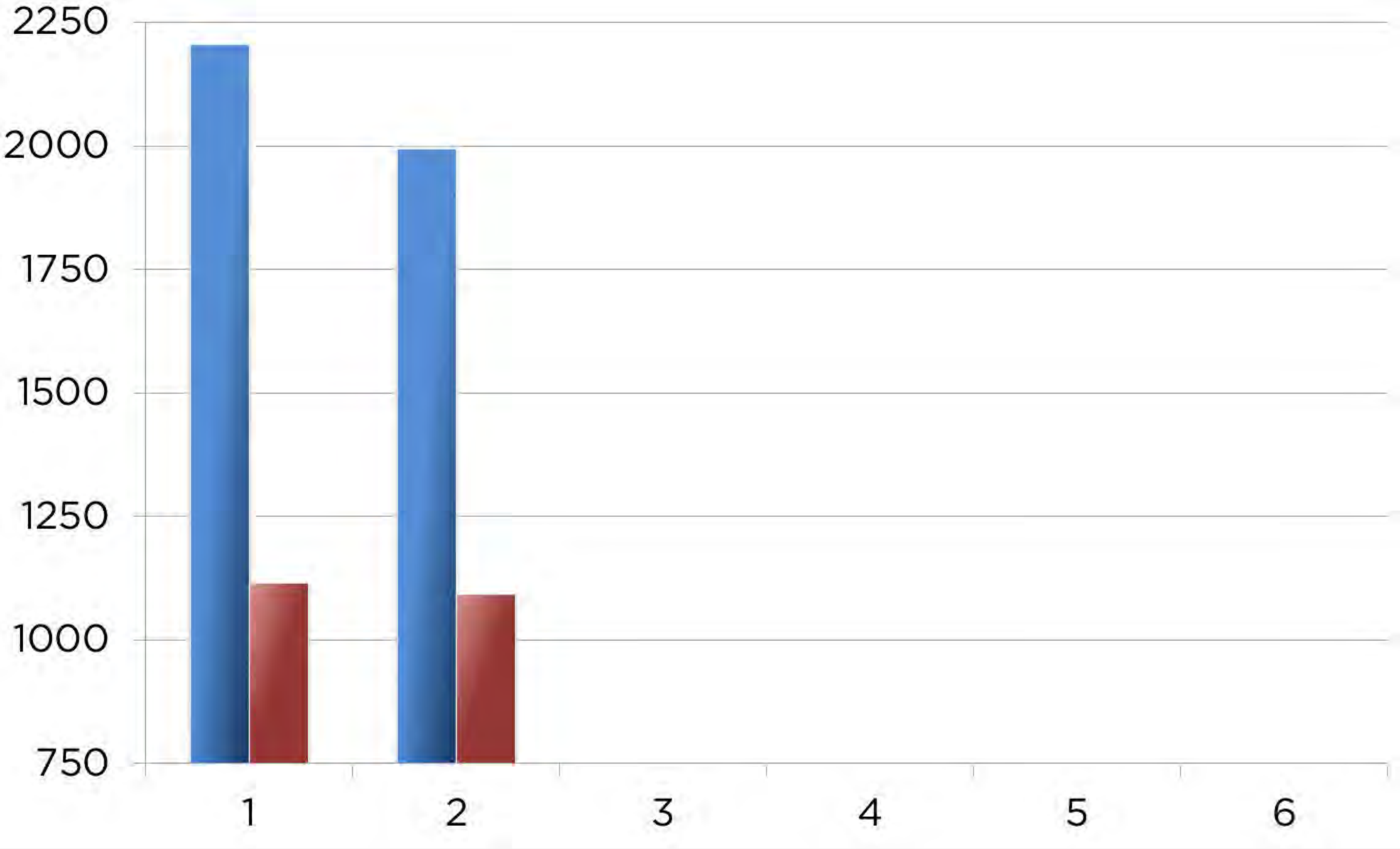
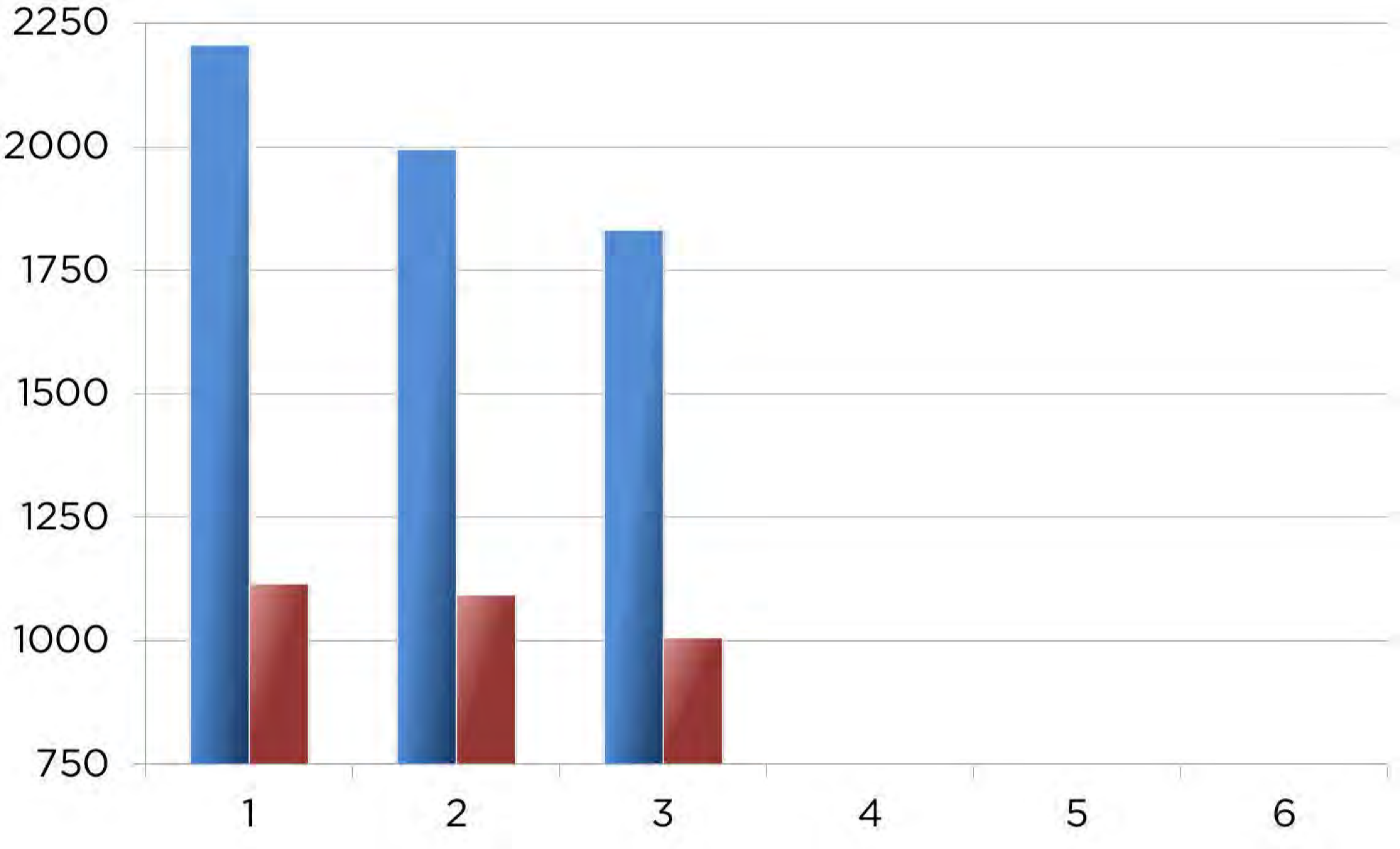


Iterative compilation - Example



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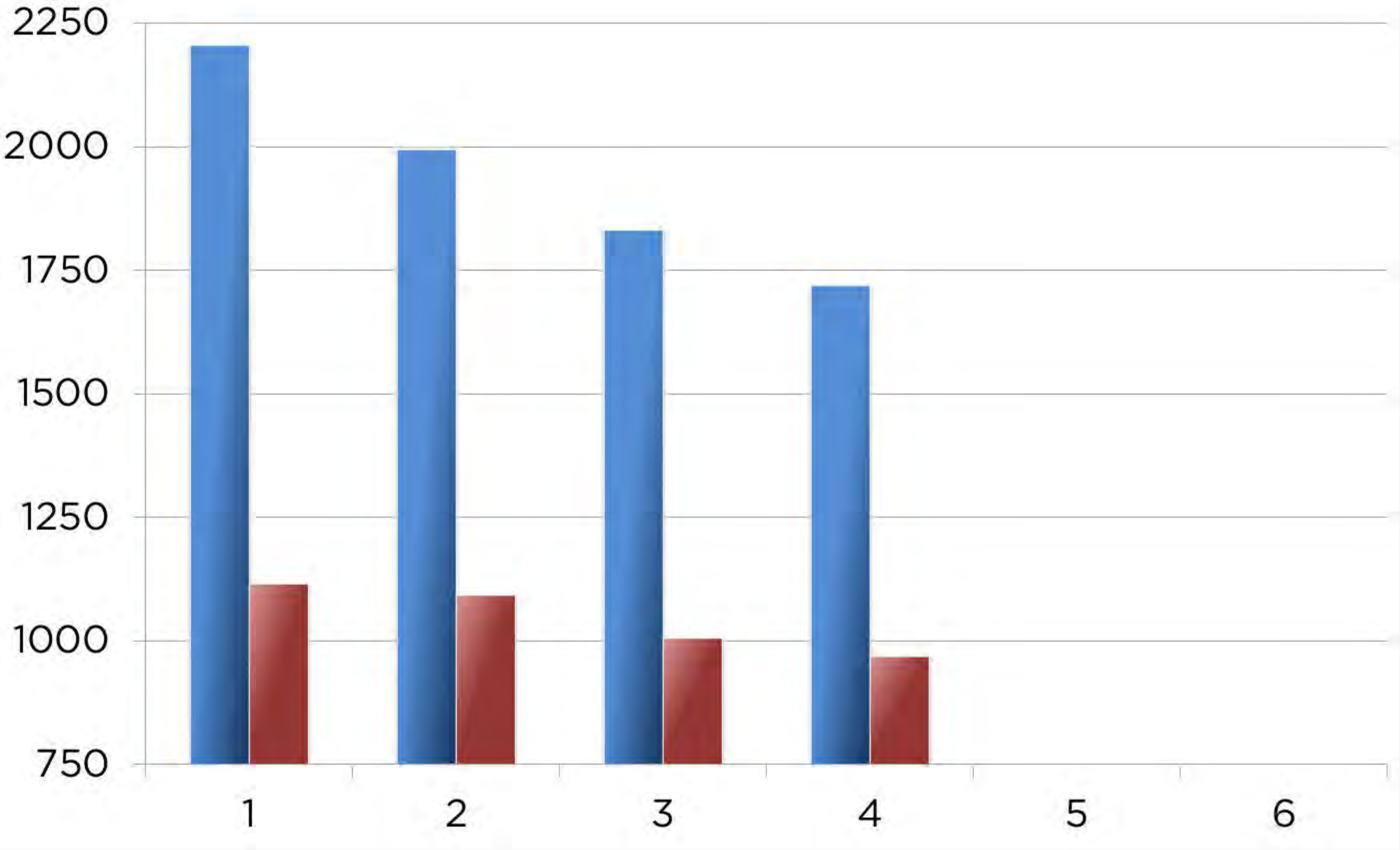

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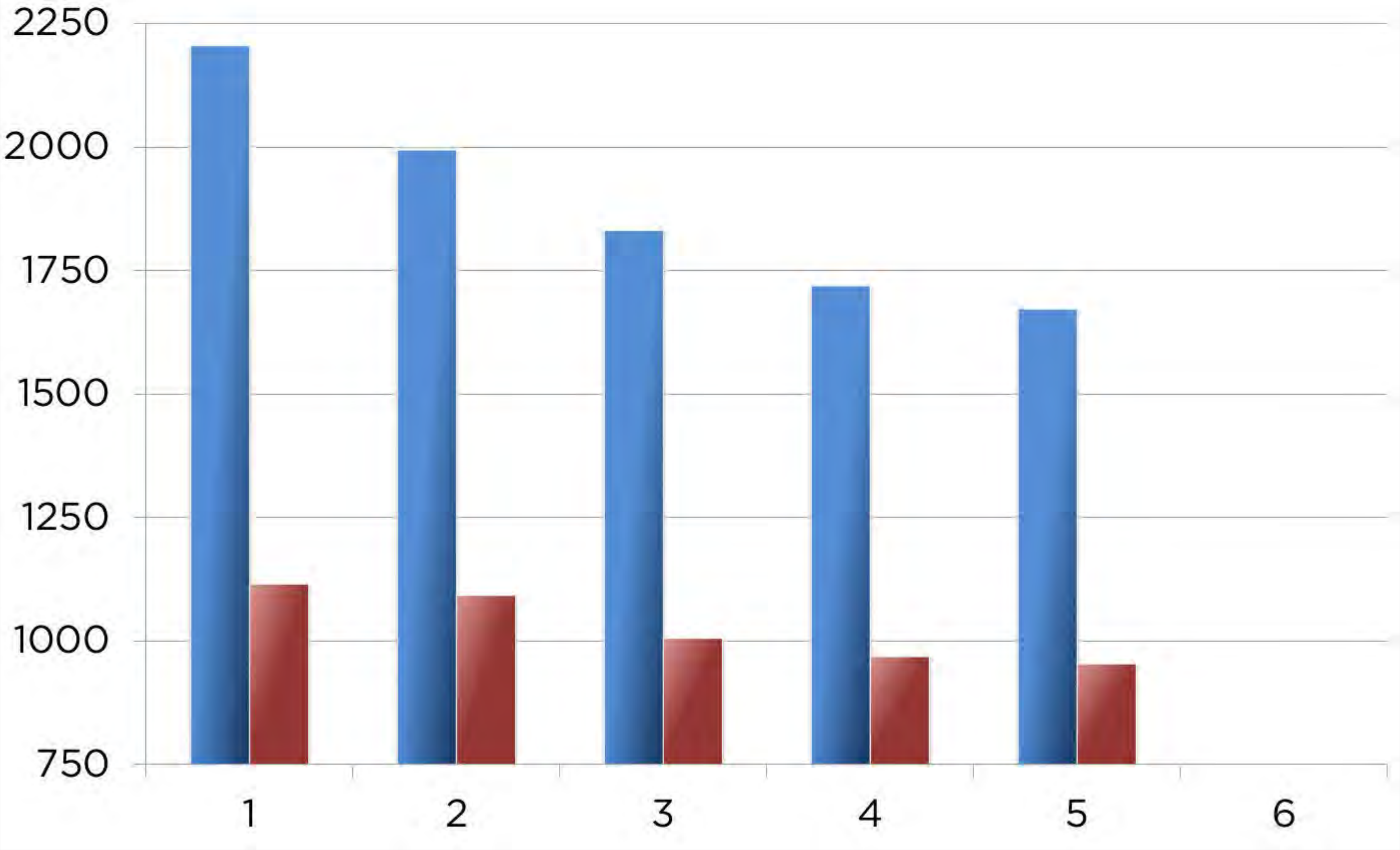

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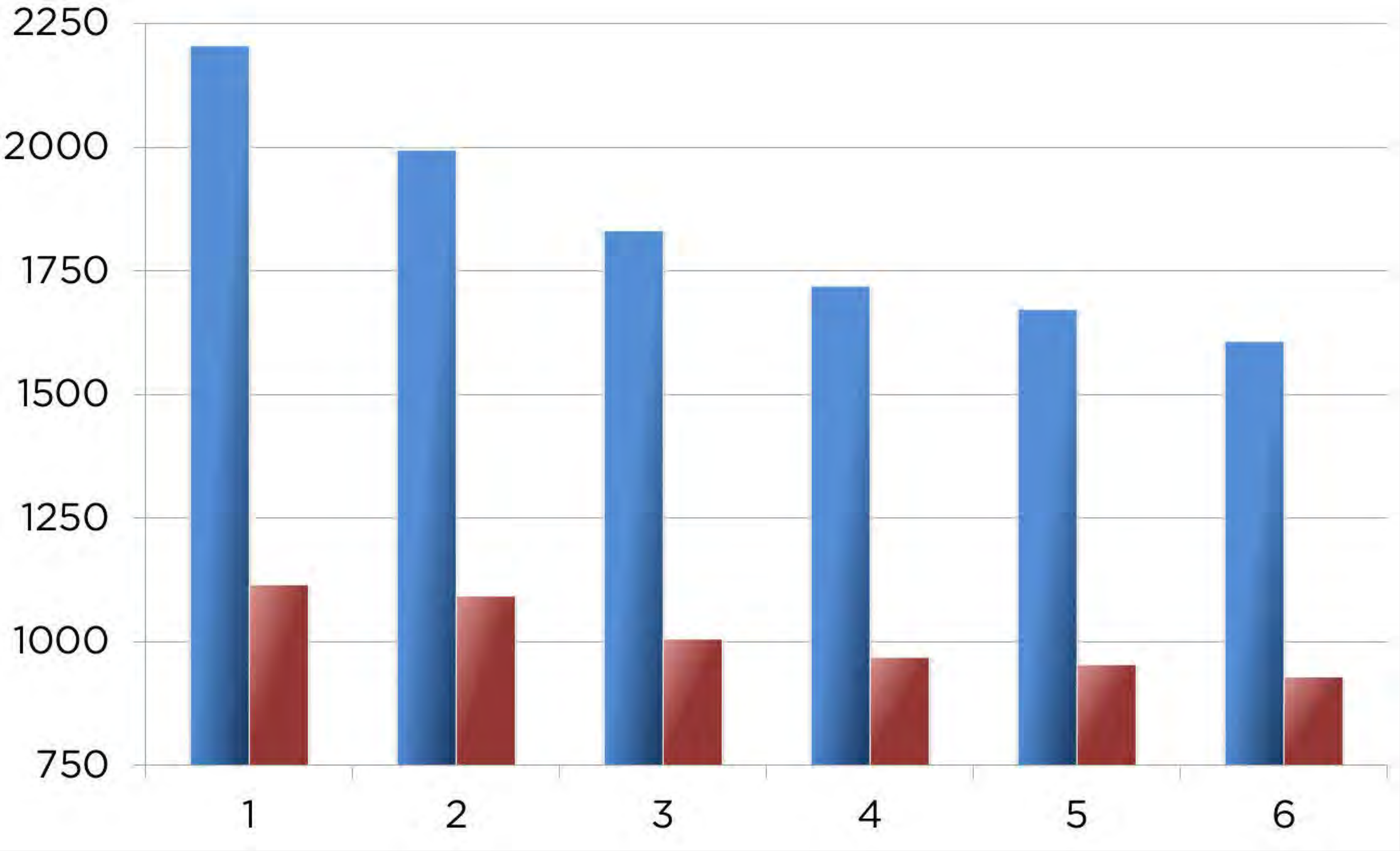

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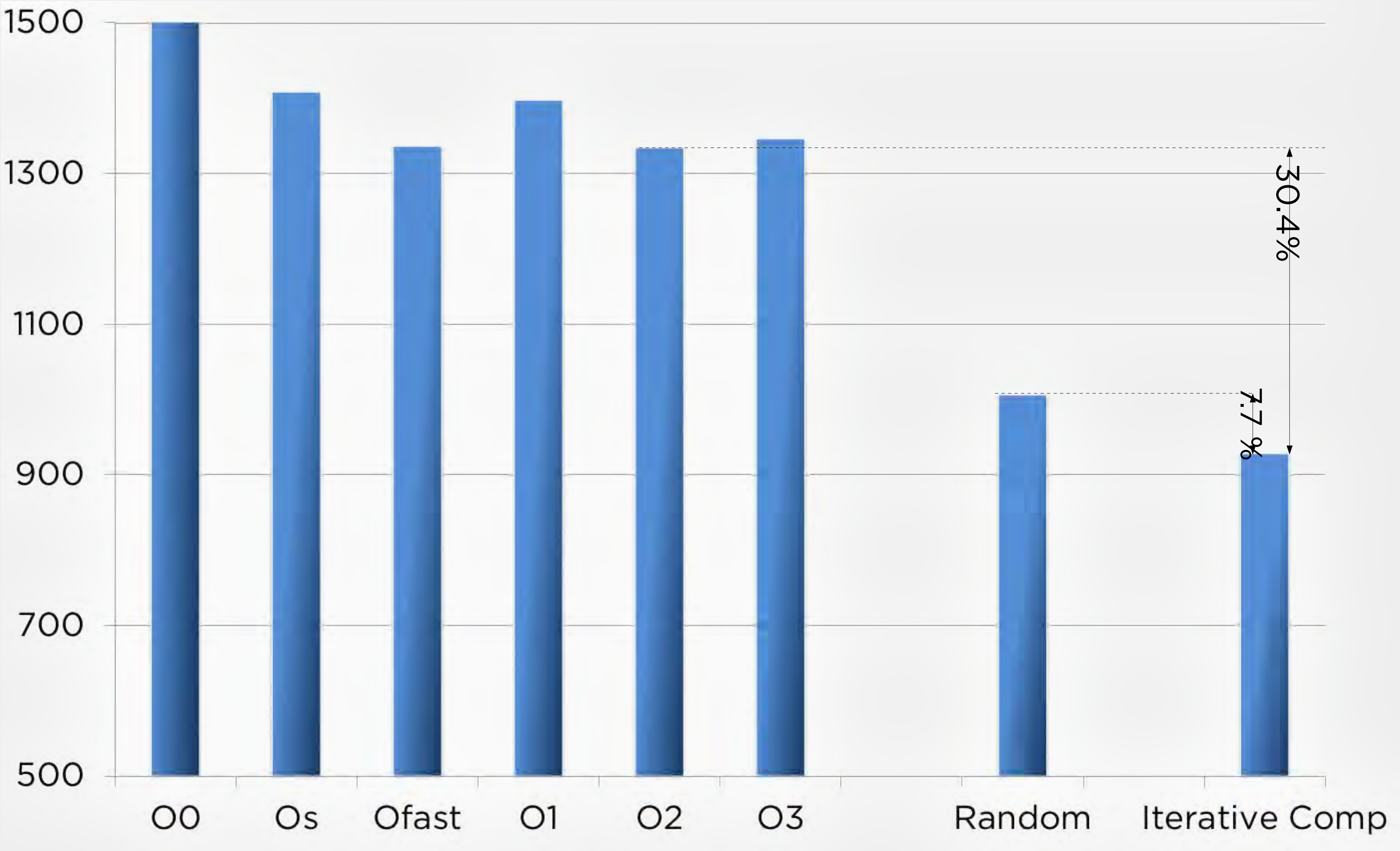


Caveats

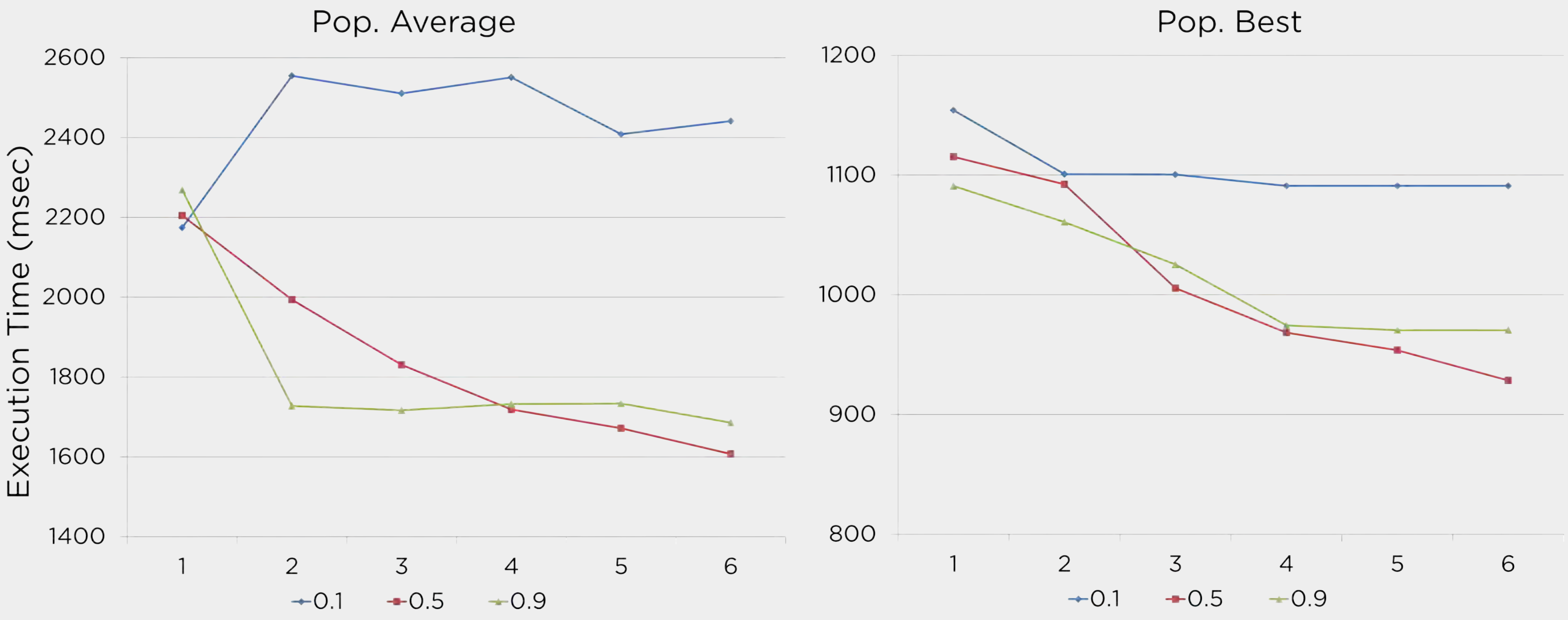
- Local maxima
- Noise
- Compiler errors

Local Maxima

- Wide & shallow vs narrow & deep search
  - Wide and shallow search not bothered by local maxima, but slow
  - Narrow and deep search focuses on local maxima, but might miss the optimal
- Algorithms and their parameters chosen to control this trade-off

Local Maxima - Example

- GA with tournament selection
  - Various tournament selection probabilities



Noise

- Noise makes iterative compilation less efficient

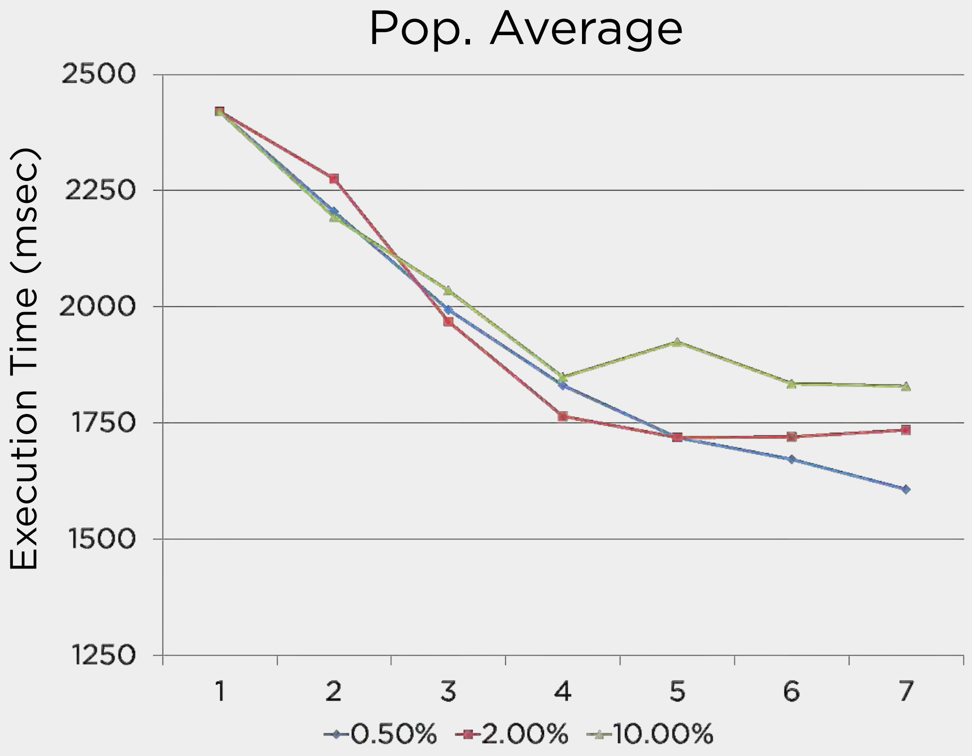
Noise

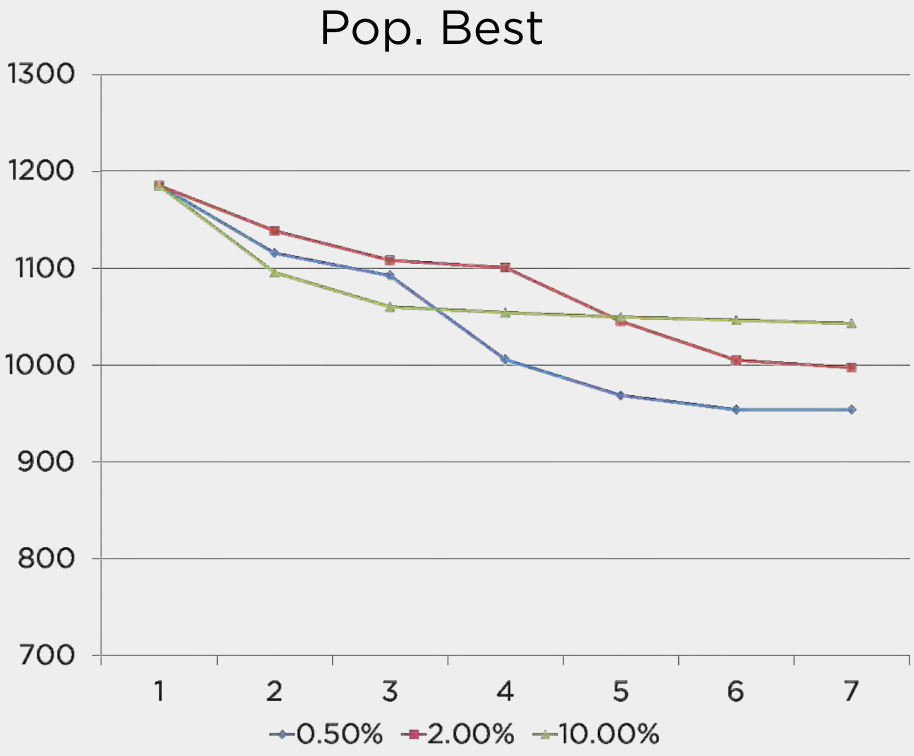
- Noise makes iterative compilation less efficient
- If noise comparable to the performance variation in the population

→ search algorithm becomes random

Noise - Example

- libquantum + gaussian noise





Noise

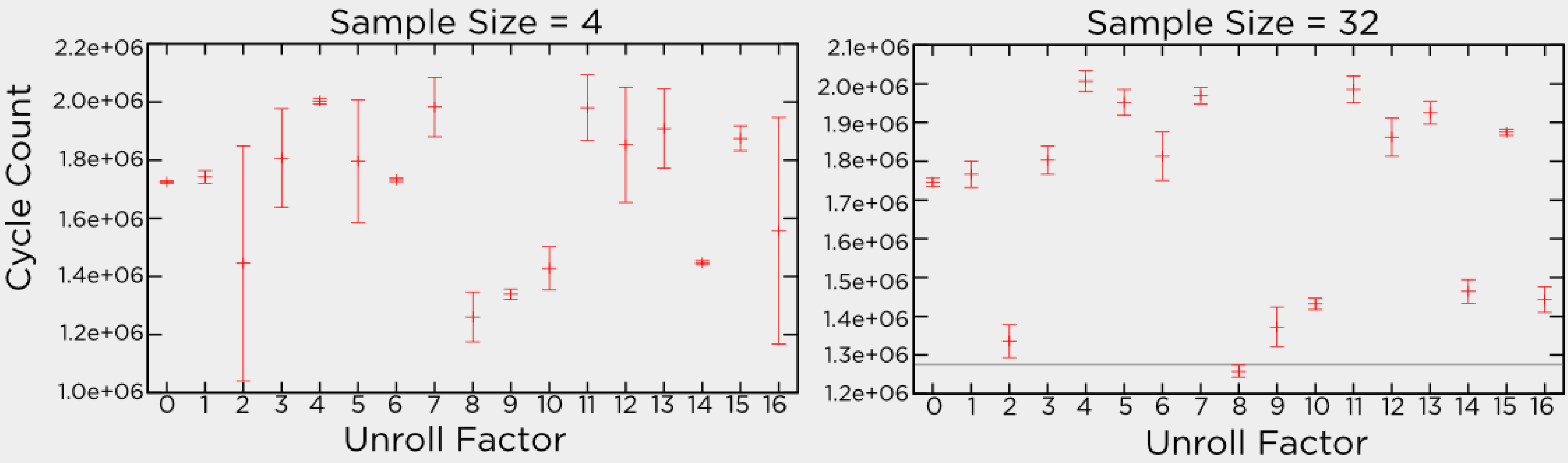
- Multiple observations to establish with some certainty the runtime of an executable

    → Higher evaluation overhead

    → slow

Noise

- Do we need high certainty?



Noise

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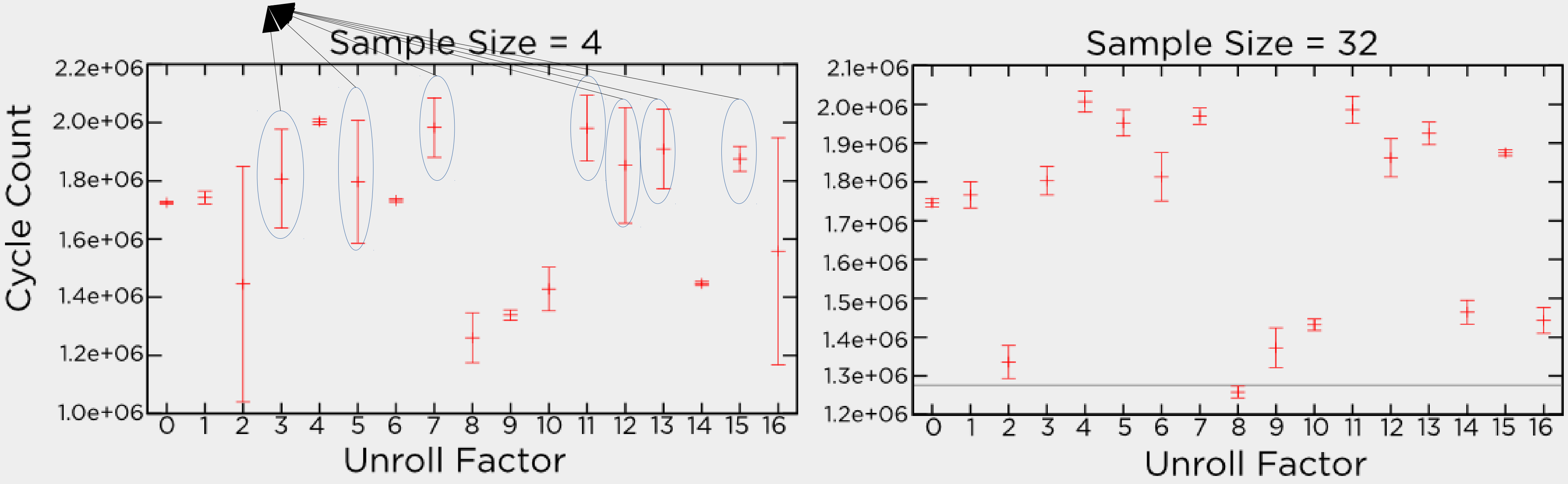
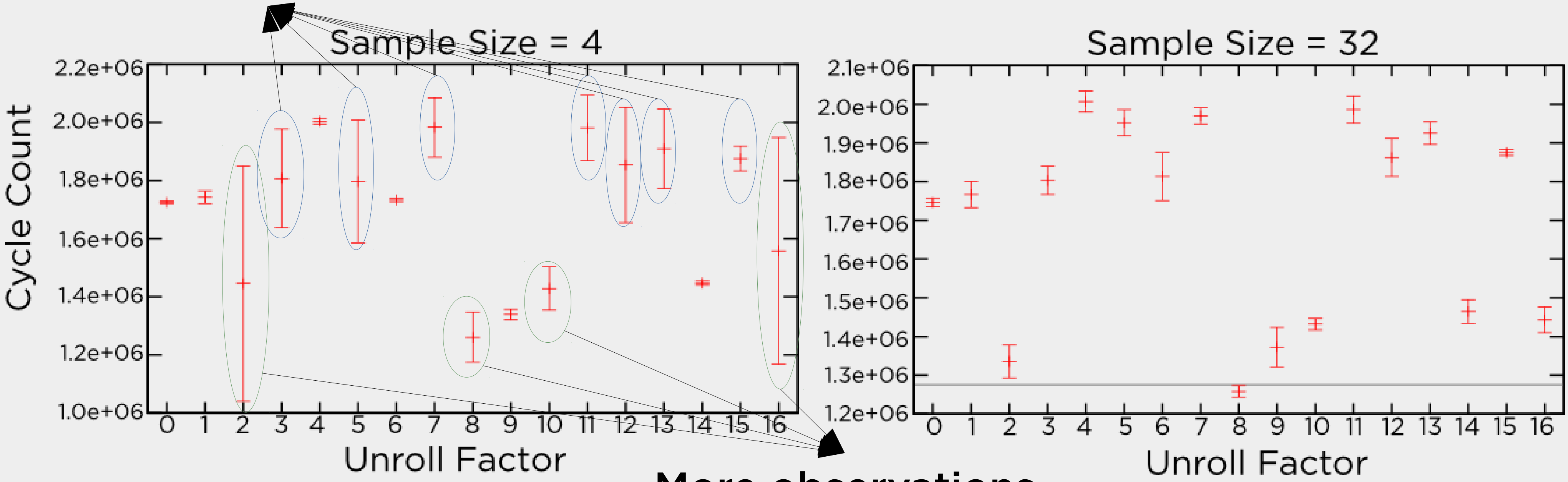


Do we care?

Noise

- Do we need high certainty?

Not really



More observations

Compiler Errors

- By randomly combining optimisations we enter an uncharted area
- Some combinations crash the compiler:
  - They don't work together and we know it
  - They don't work together and we don't know it
  - They trigger unknown bugs in the compiler code
- Crashes affect the speed of iterative compilation
  - Time wasted on unsuccessful builds
  - Benefit if we find problematic combinations early

Compiler Errors

- Others affect the program correctness
  - Due to bugs or unsafe transformations
- How do we handle them?
  - Fully deterministic behaviour
  - Output sensitive on changes in the control flow
  - Validation of the output after each execution

Improving iterative compilation

- Focus searching on areas predicted to be near optimal
  - Human expert input
  - Analytical models
- Pruning of irrelevant/harmful transformations
- Reduce evaluation overhead
  - Iterative compilation on the function call level

Iterative compilation - Drawbacks

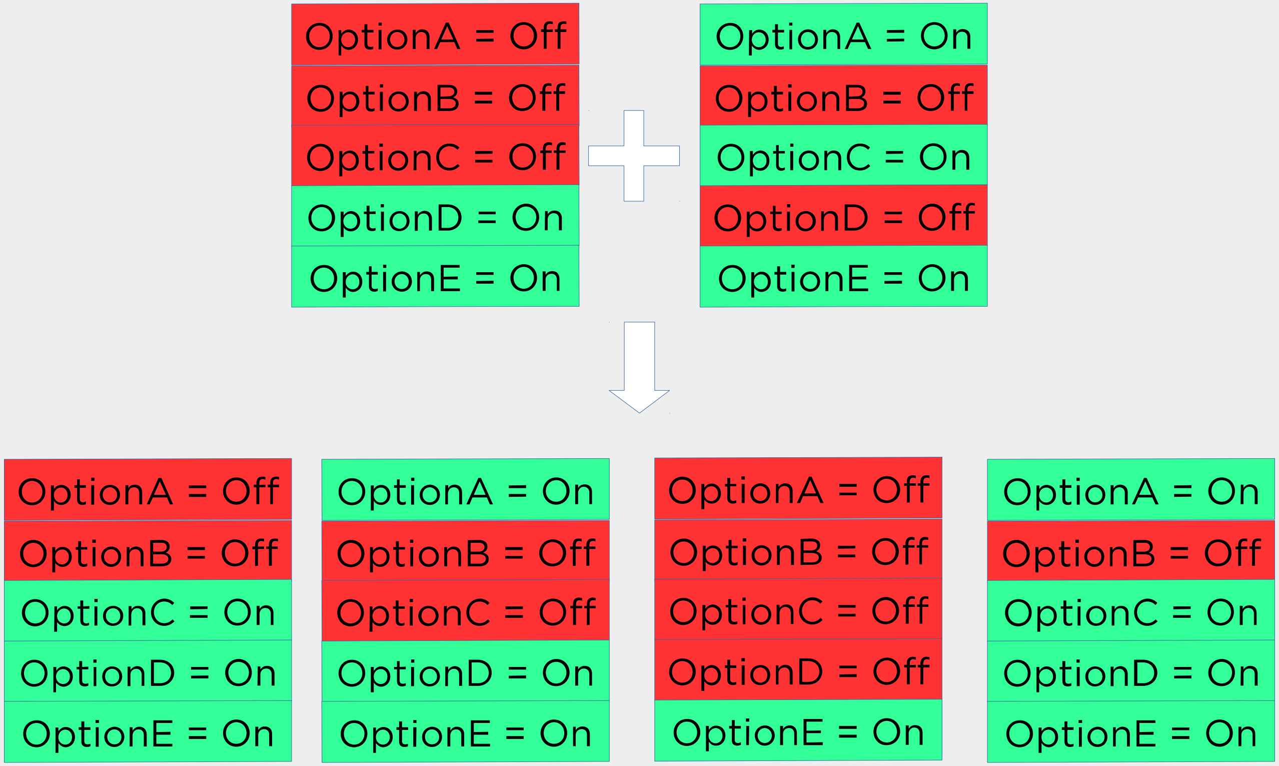
Iterative compilation - Drawbacks

- Takes too long
  - Hours to month for the search to terminate
- Search parameters might need to be hand tuned
- Still, it's worth the effort for:
  - embedded systems
  - libraries
  - and others

Beyond iterative compilation

- Most of the cost → evaluation
  - 1000s of evaluations
  - To the garbage bin when we complete the search
- Can we somehow reuse the evaluation results for different programs?

Genetic Algorithm - Example



OptionA = Off	OptionA = On
OptionB = Off	OptionB = Off
OptionC = Off	OptionC = On
OptionD = On	OptionD = Off
OptionE = On	OptionE = On

OptionA = Off	OptionA = On	OptionA = Off	OptionA = On
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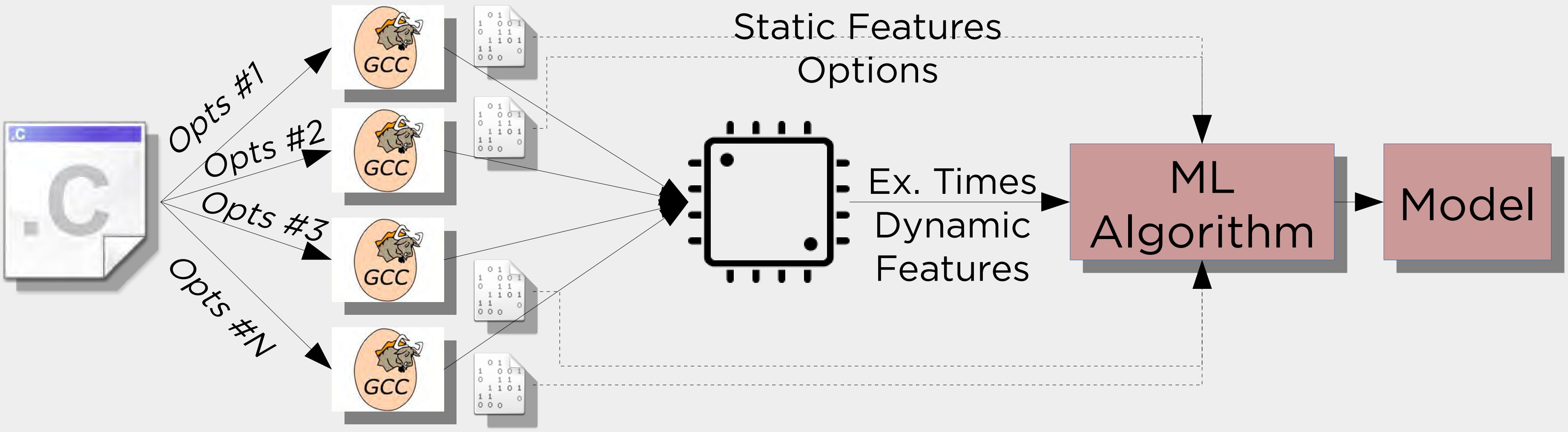
OptionC = On	OptionC = Off	OptionC = Off	OptionC = On
OptionD = On	OptionD = On	OptionD = Off	OptionD = On
OptionE = On	OptionE = On	OptionE = On	OptionE = On

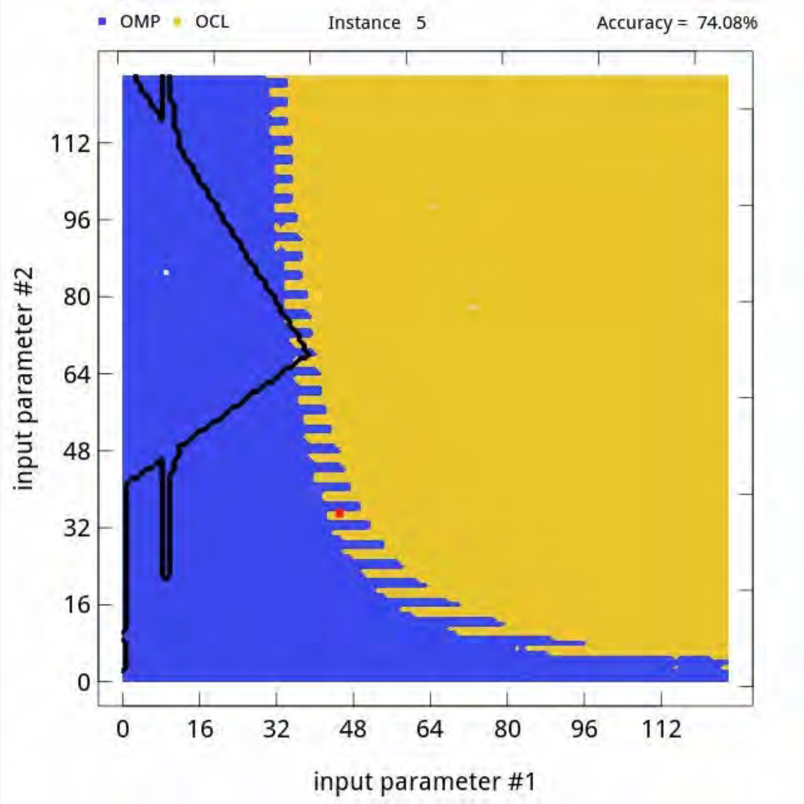
ML-based optimising compiler

- Choose options
- Build
- Evaluate
- Train



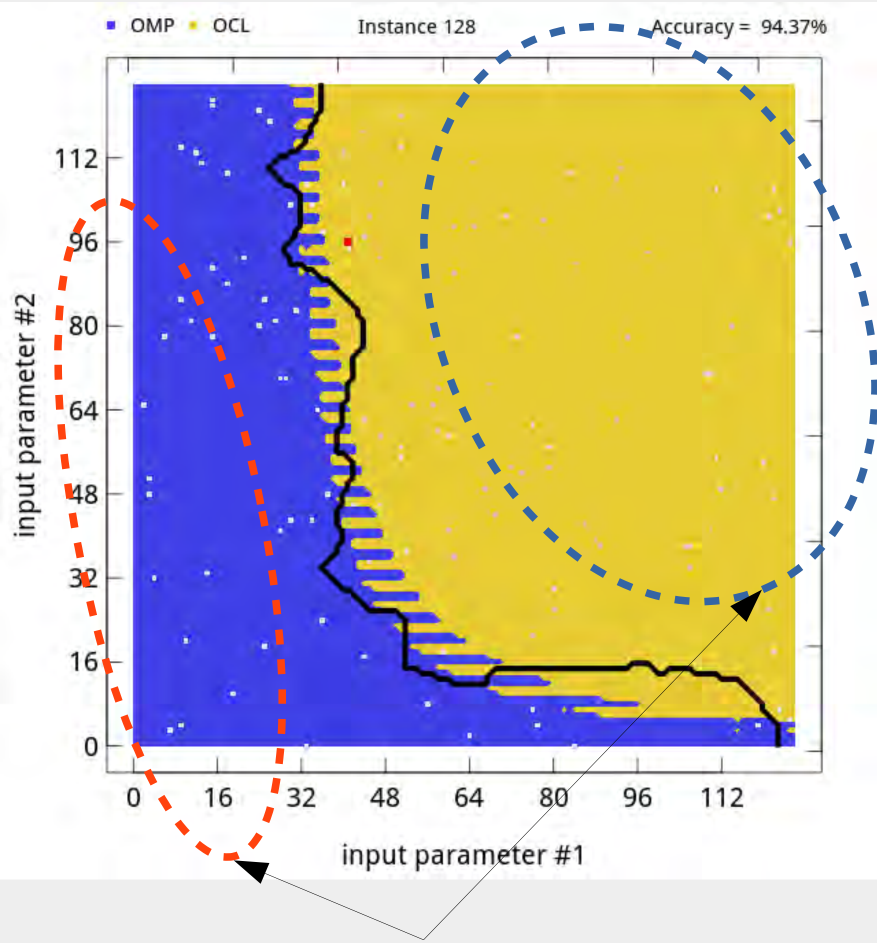
Example

- Best device (cpu or gpu) for an app based on the input size
  - Hotspot benchmark, 2d input
  - Random input sizes evaluated
  - Model built with the nearest neighbour algorithm



Example

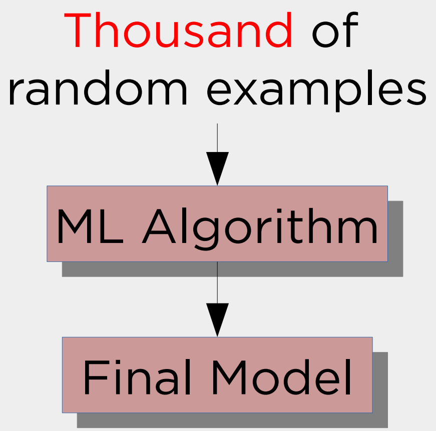
- Most points offer little to no information → don't improve the model

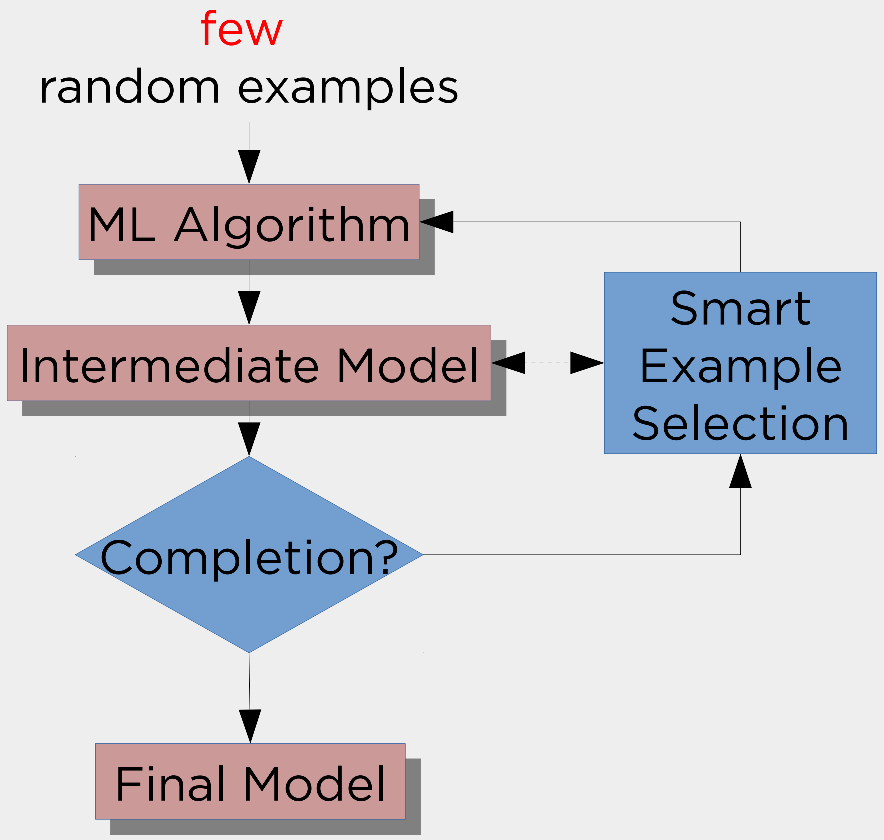


Waste of time

Active Learning

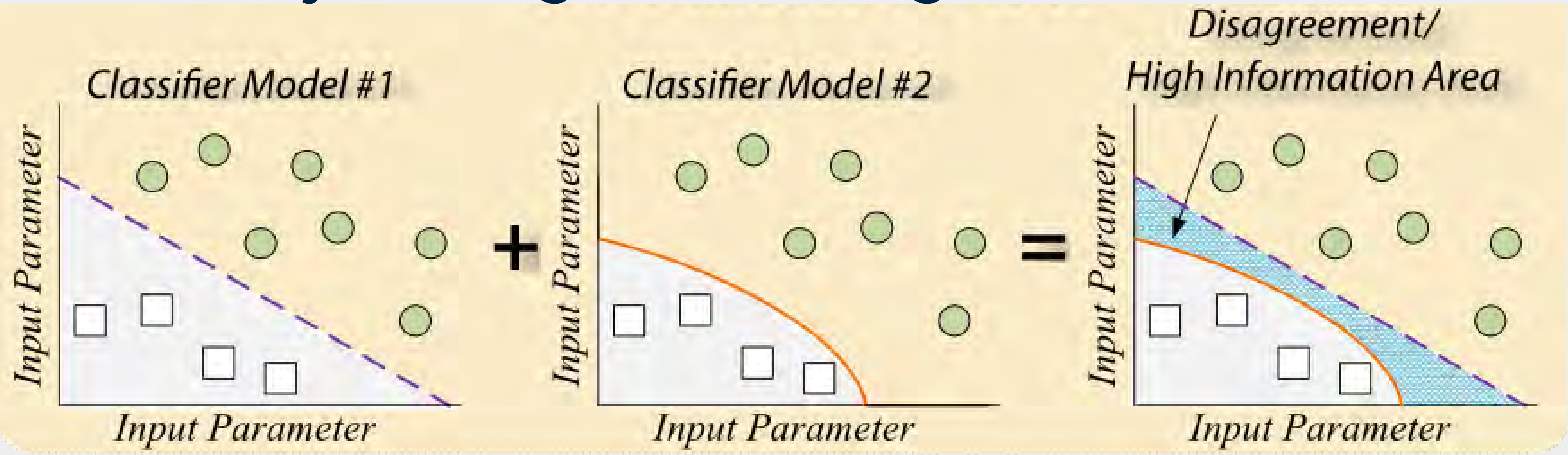
- Random training points selection wasteful
- Active Learning



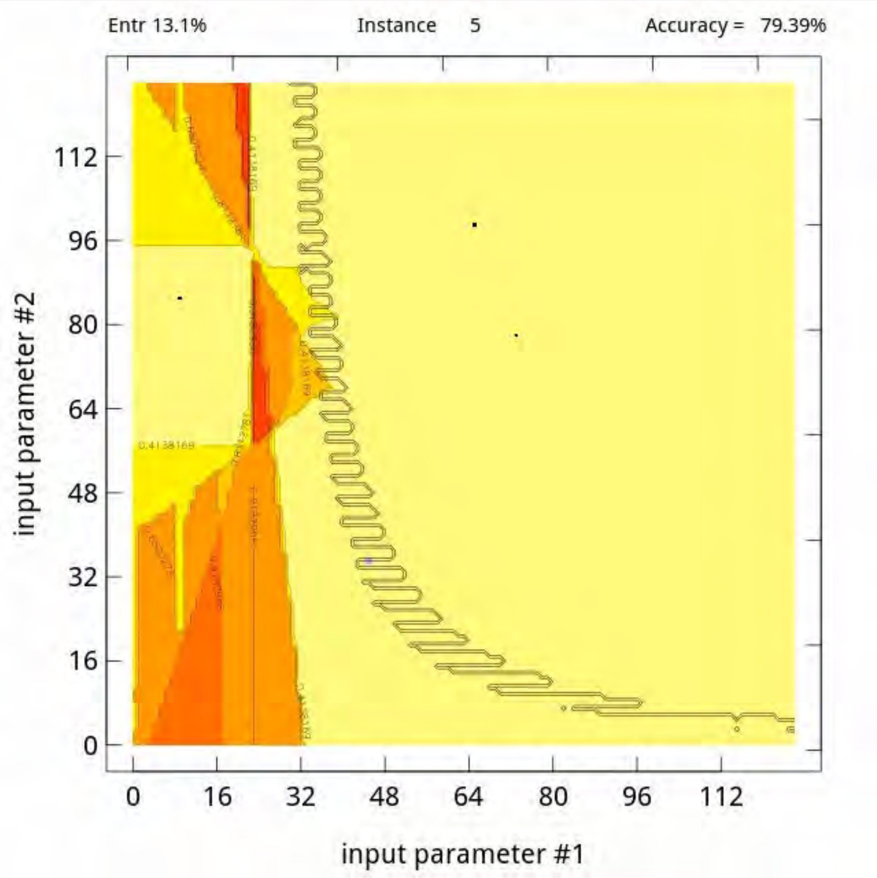


Active Learning

- Best points → High information points
  - close to the cpu-gpu border
  - max uncertainty about the best device
- Quantifying uncertainty:
  - Multiple ML algorithms trained with the same points
  - Uncertainty == degree of disagreement

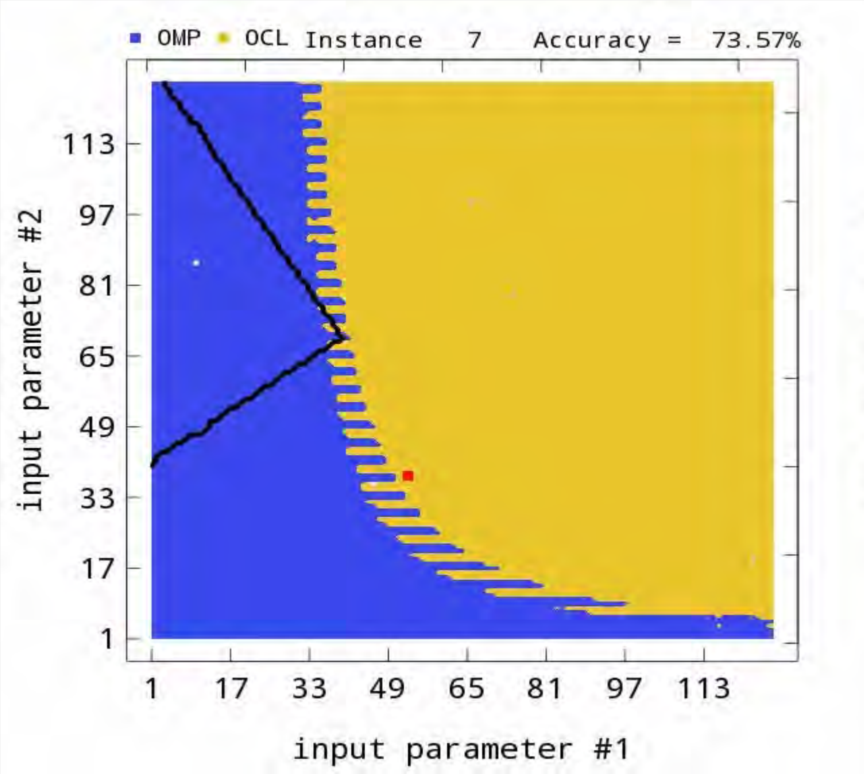


Disagreement



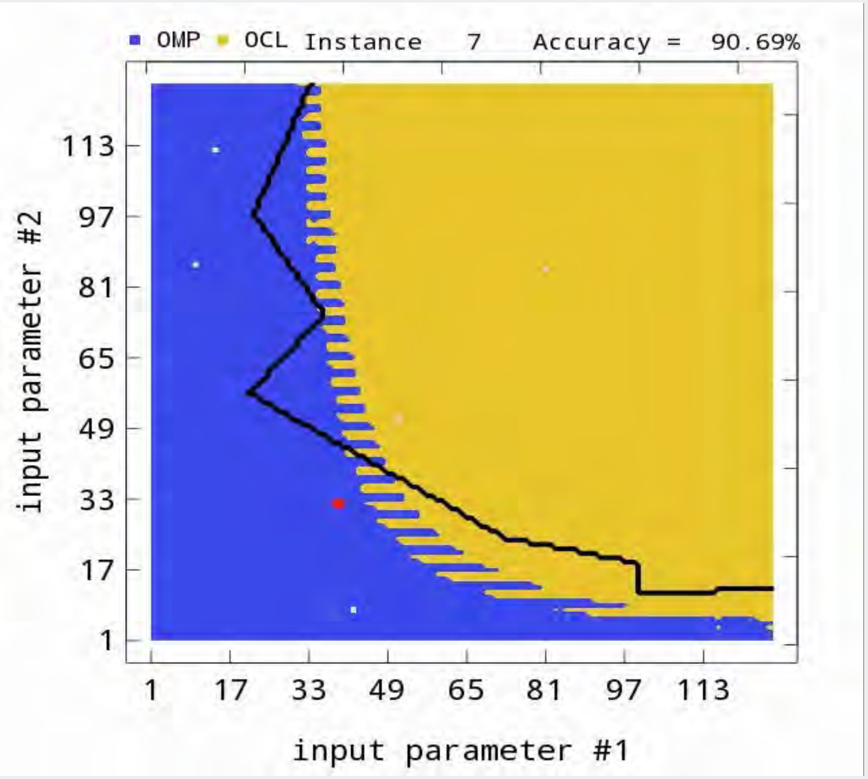
Comparison

Random



130 training points for 95% accuracy

Active Learning



85 training points for 95% accuracy

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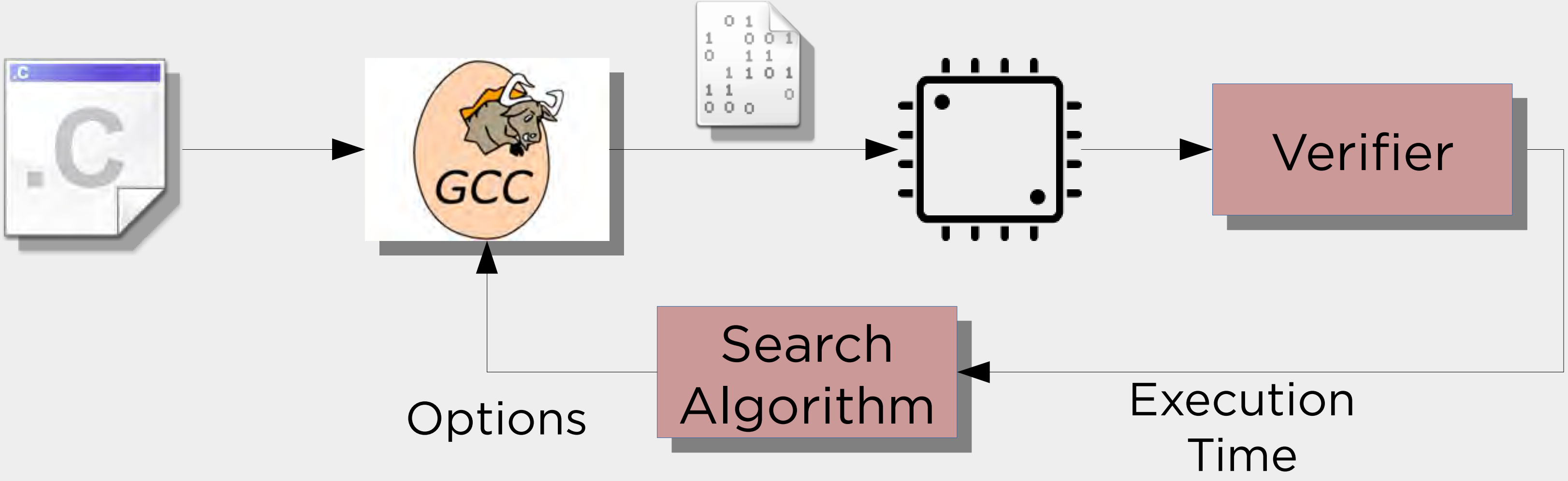
.C
GCC
Verifier
Search Algorithm
Options
Execution Time