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Title: A Rigorous Comparison of the D-Wave 2X QPU to Established B-QP Solution Methods

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Bent, Russell Whitford

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advanced network science initiative (ansi)

A Rigorous Comparison of the D-Wave 2X QPU to Established B-QP Solution Methods

Carleton Coffrin, Harsha Nagarajan, Russell Bent

A-1 & T-5

UNCLASSIFIED

D-Wave for Optimization

Binary-Quadratic Program
(B-QP / QUBO)

NP-Hard Combinatorial Optimization Problem

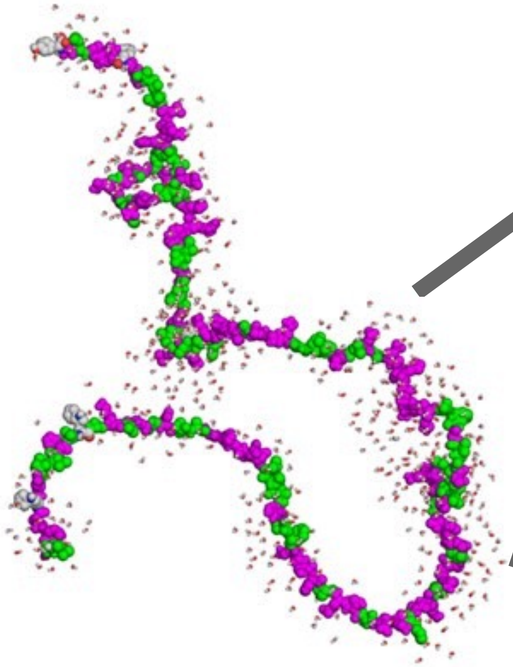
The Benchmarking Question

BIG DEAL!

State-of-the-Art Optimization Tools

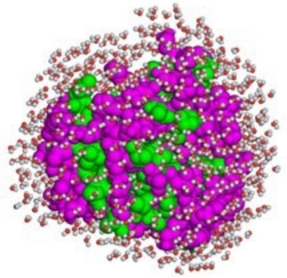
D-Wave

A Preferable Benchmarking Situation



Protein Folding

Current State-of-the-Art



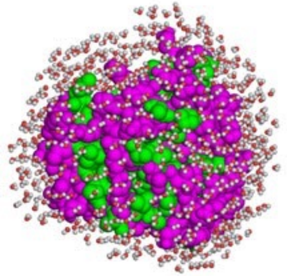
Claim: On this problem,

D-Wave is state-of-the-art.

The ends justify the means.

Better?

D-Wave Based Algorithm



The Benchmarking Problem

ISTI ‘16

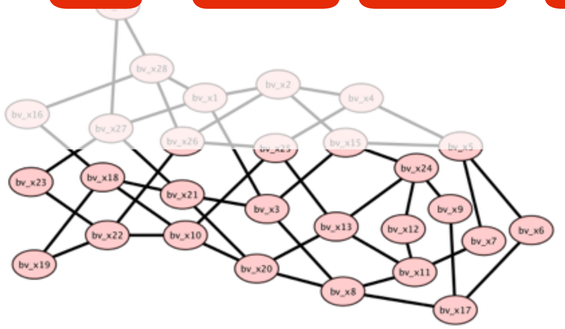
QPLIB

DIMACS

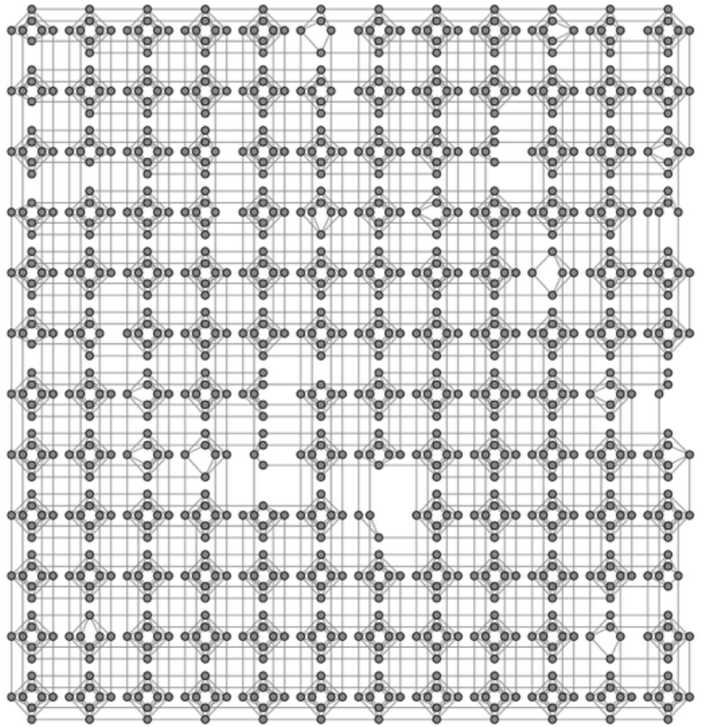
Max-Clique

FAIL

Embedding

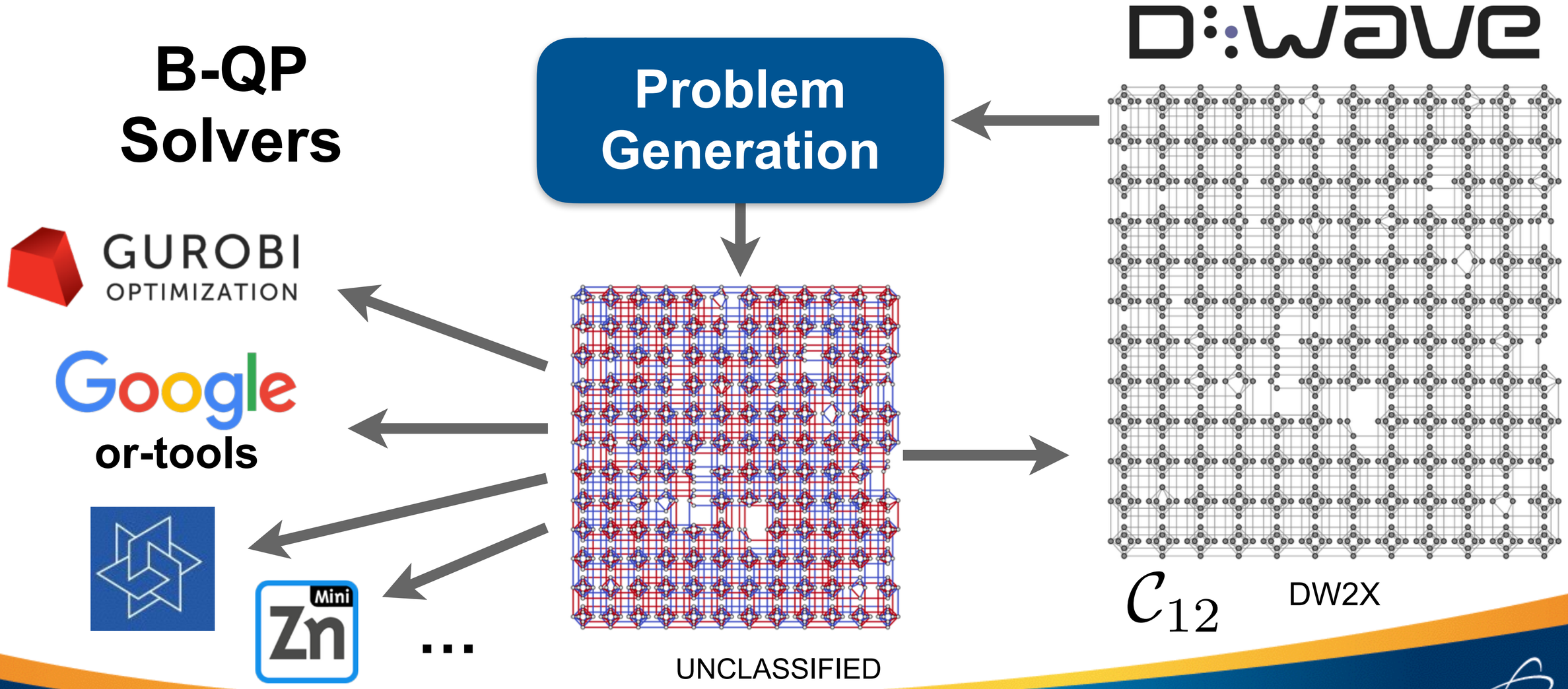


D-Wave



C_{12} DW2X

A Benchmarking Stopgap

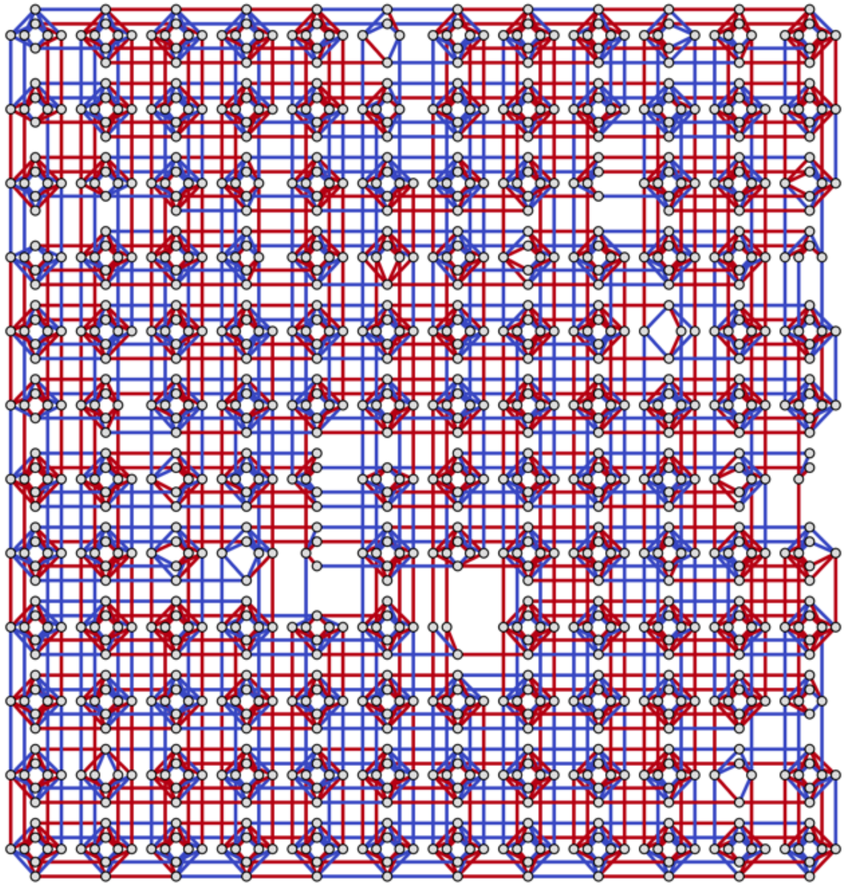


Problems with Problem Generation

- How **hard** are randomly generated problems?
- Lessons learned from **Random SAT**

AAAI-92

Example: What's the Difference?

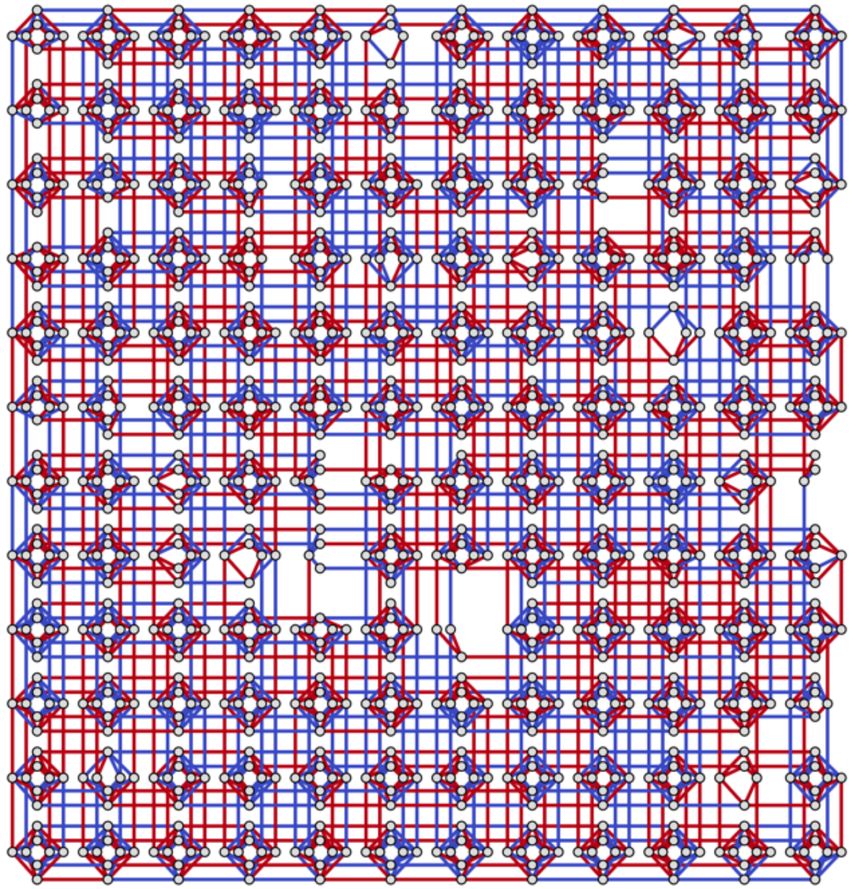


HARDEST

super frustrated system

EASIEST

ferromagnet in disguise!



The Key Challenge

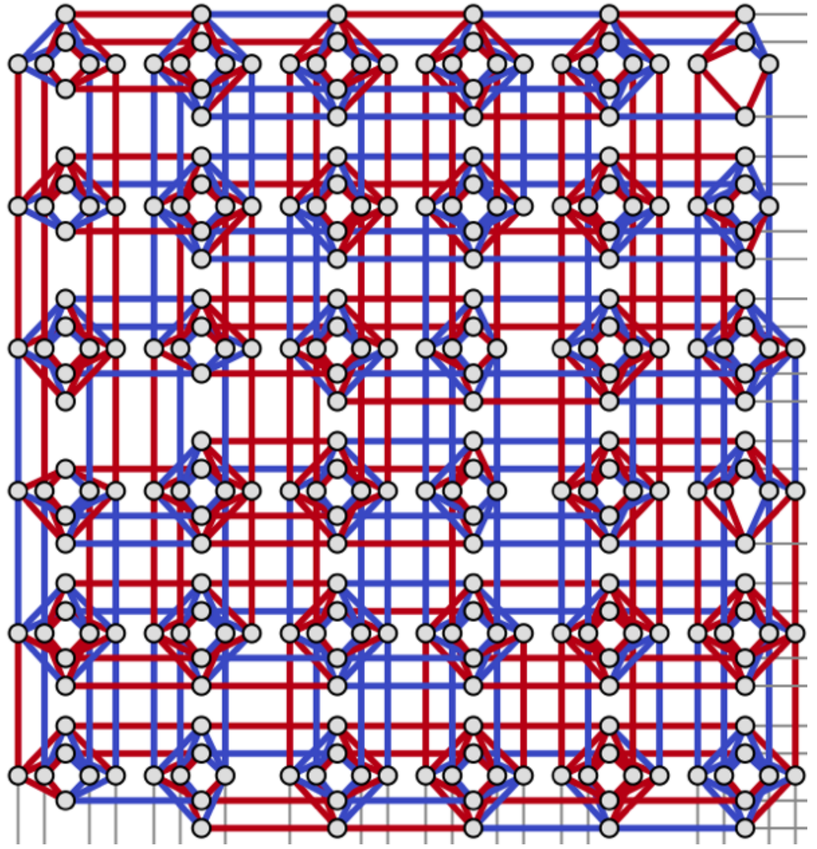
How to generate a **HARD** D-Wave case

look to the literature

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

Proposed Problem Generators

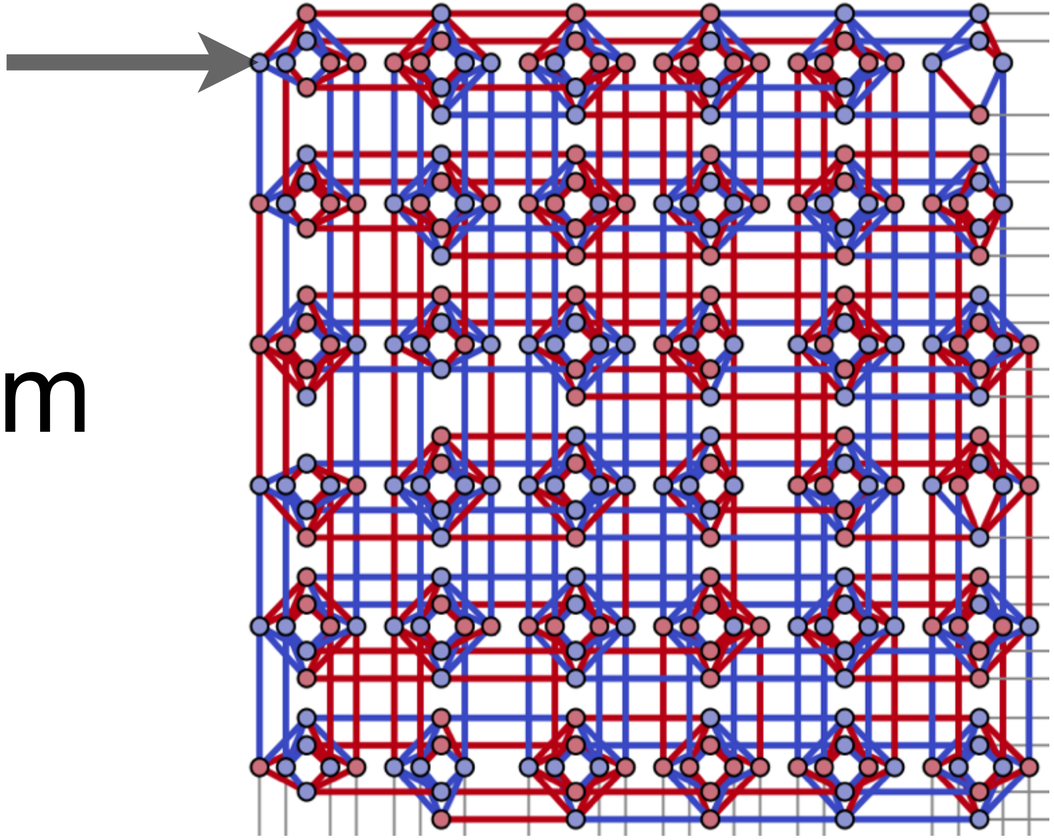
- **RAN-k**
  - set field to zero
  - set couplers at random
  - use k discrete steps



https://arxiv.org/abs/1508.05087

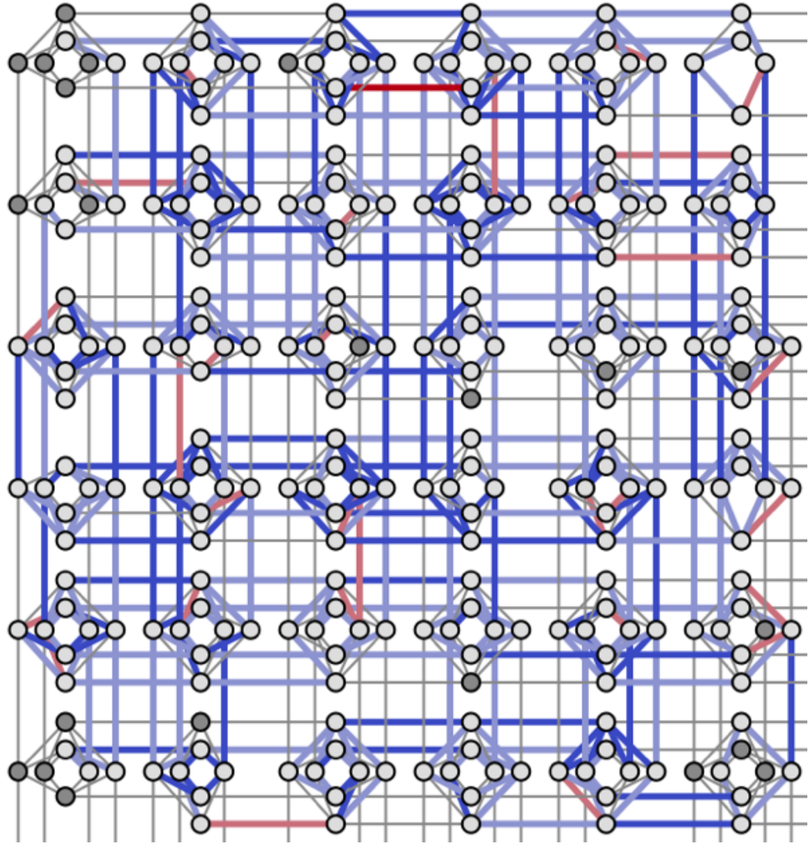
Proposed Problem Generators

- **RANF-k**
  - set field at random
  - set couplers at random
  - use k discrete steps



Proposed Problem Generators

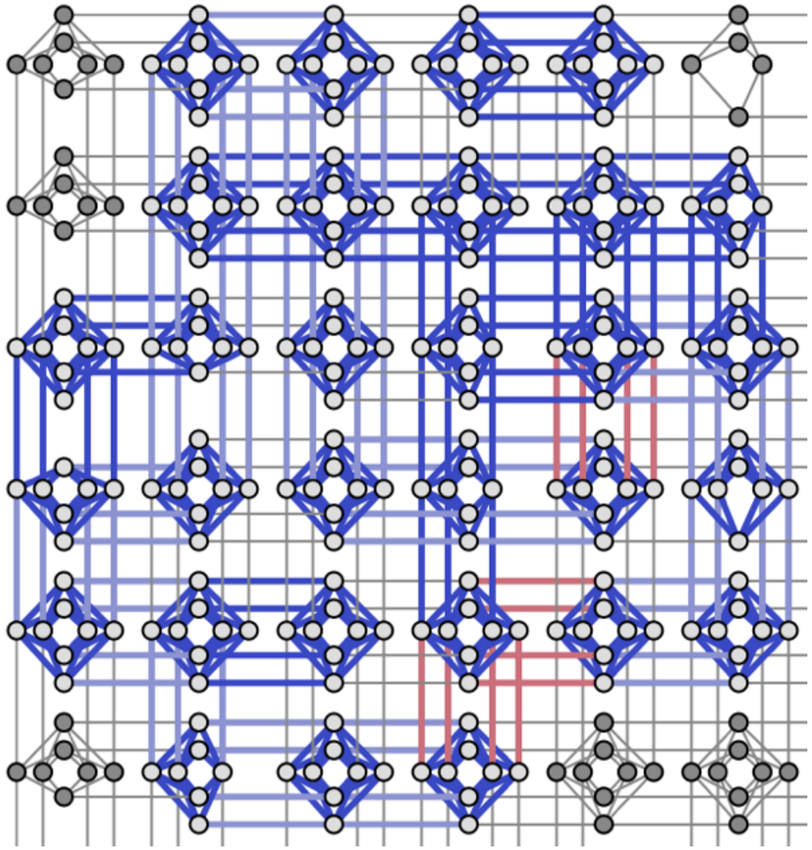
- Frustrated Loops (**FL**)
  - find random cycles
  - add one edge of frustration
  - overlay multiple cycles



https://arxiv.org/abs/1508.05087

Proposed Problem Generators

- Frustrated Cluster Loops (**FCL**)
  - find random cycles
  - add one edge of frustration
  - overlay multiple cycles



https://arxiv.org/abs/1701.04579

https://arxiv.org/abs/1703.00622

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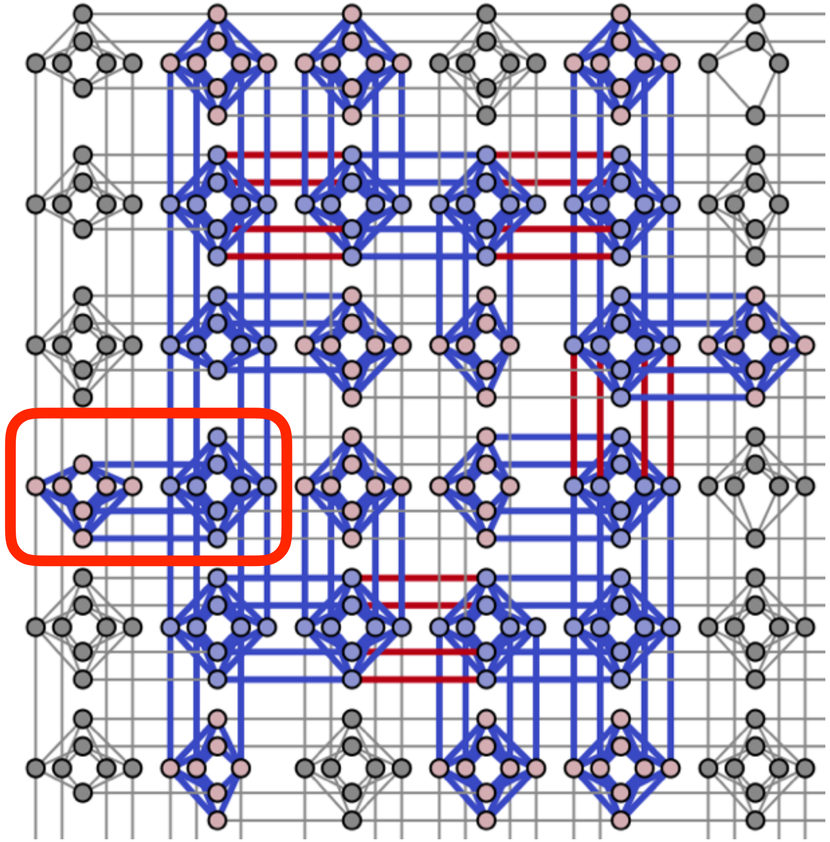
Proposed Problem Generators

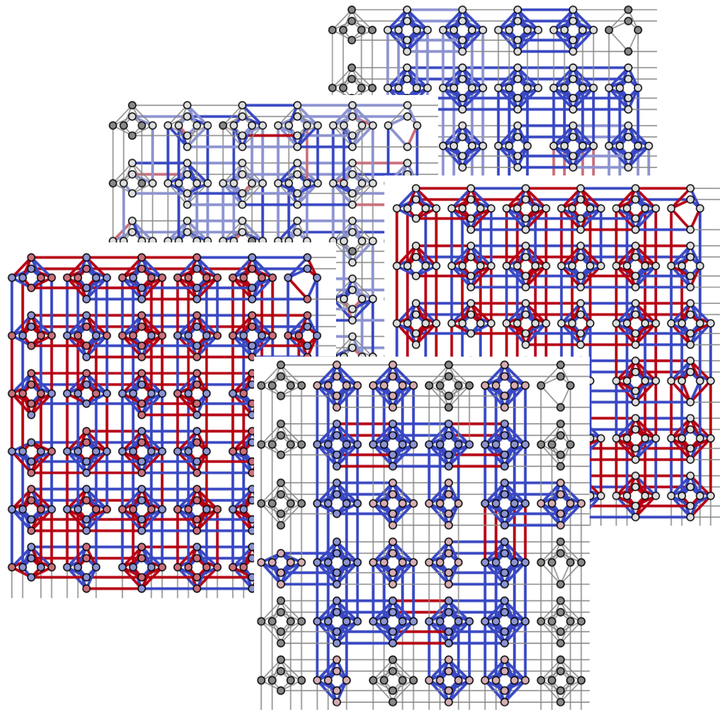
- Weak-Strong Cluster Networks (**WSCN**)
  - random grid of two cell gadgets



https://arxiv.org/abs/1512.02206

What to Compare?

Cases



?

Solvers

qbsolv

D-Wave

GUROBI OPTIMIZATION

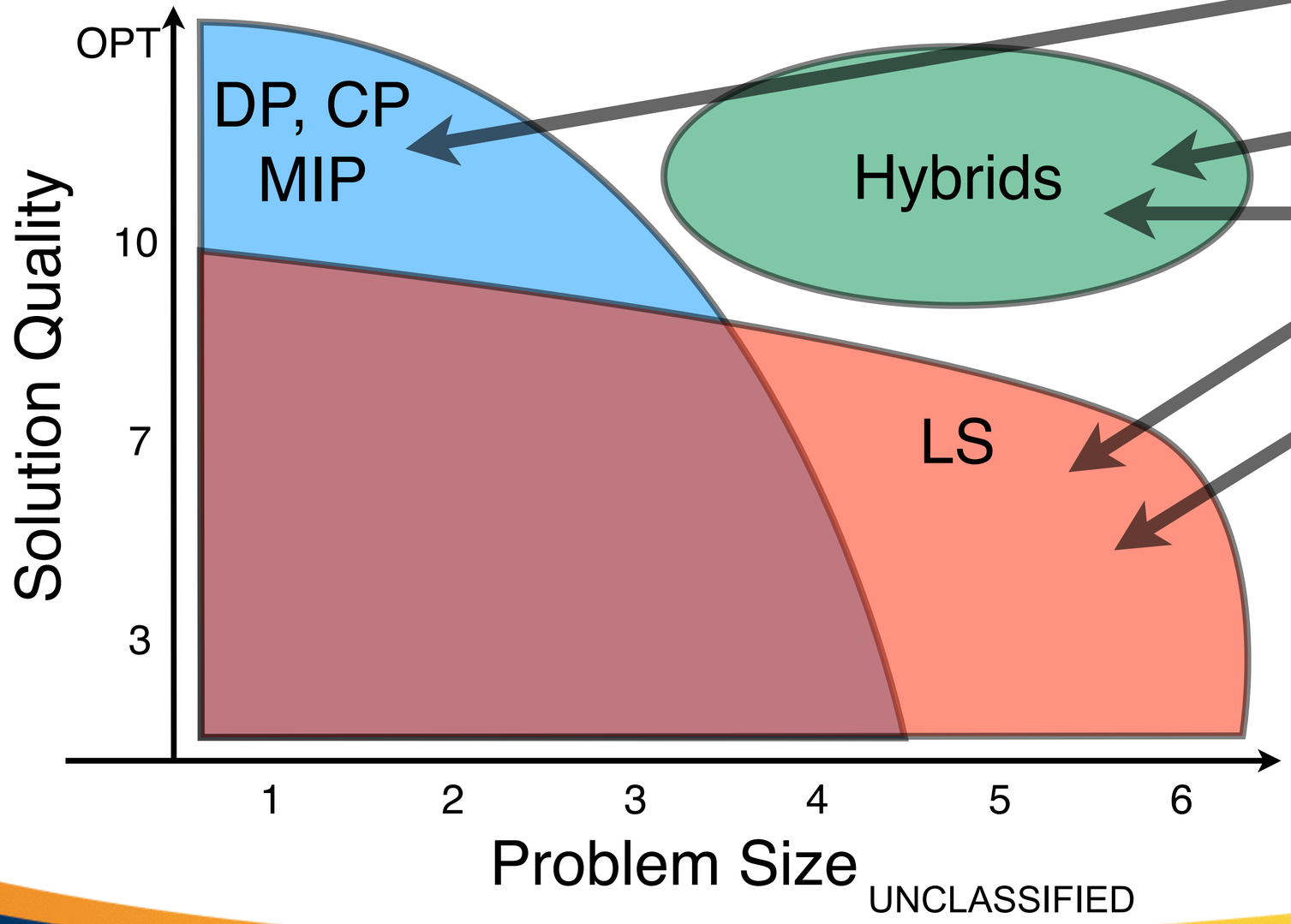
HFS

SA

Mini Zn

Google or-tools

Types of Solvers



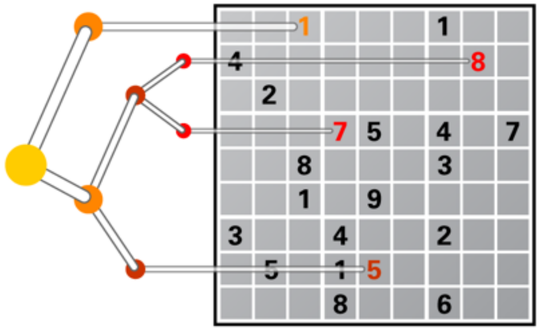
GUROBI OPTIMIZATION

HFS

D:WAVE ?

SA, Tabu Search

coursera



Discrete Optimization

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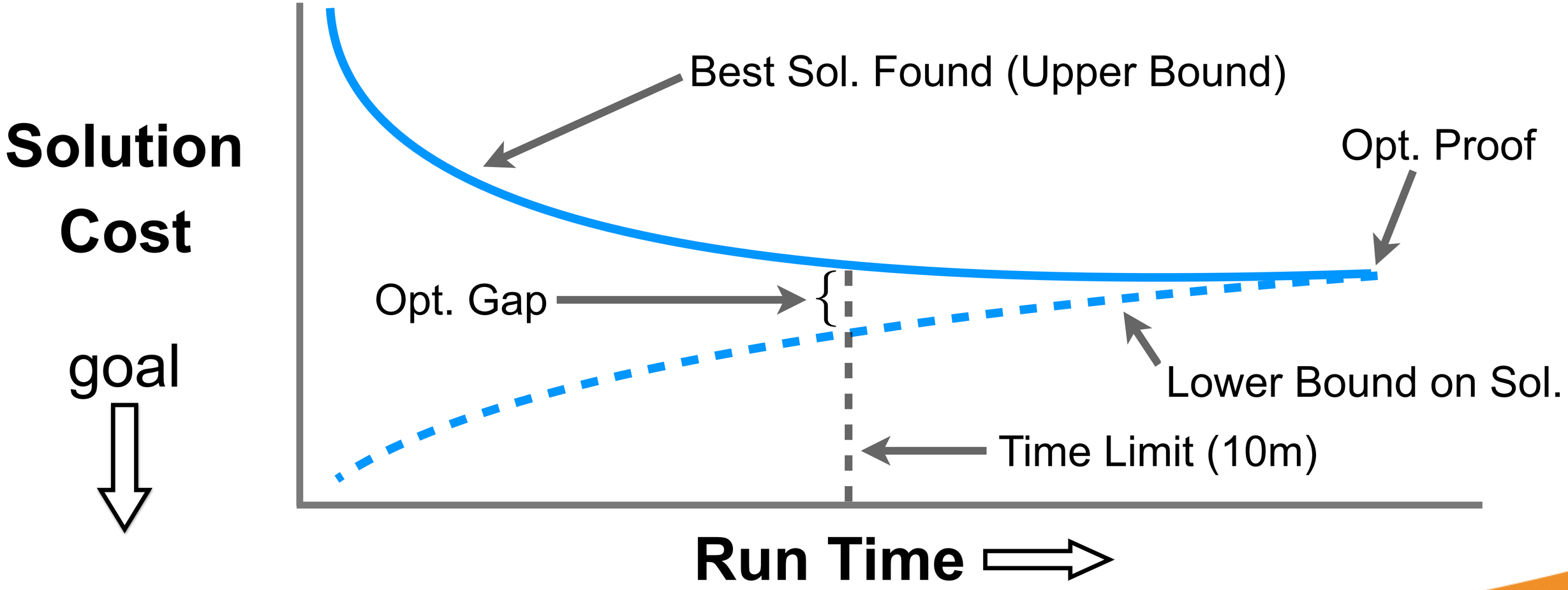
Classic B-QP Solver

GUROBI OPTIMIZATION



UNCLASSIFIED

HFS Solver

Hamze-de Freitas-Selby (HFS)

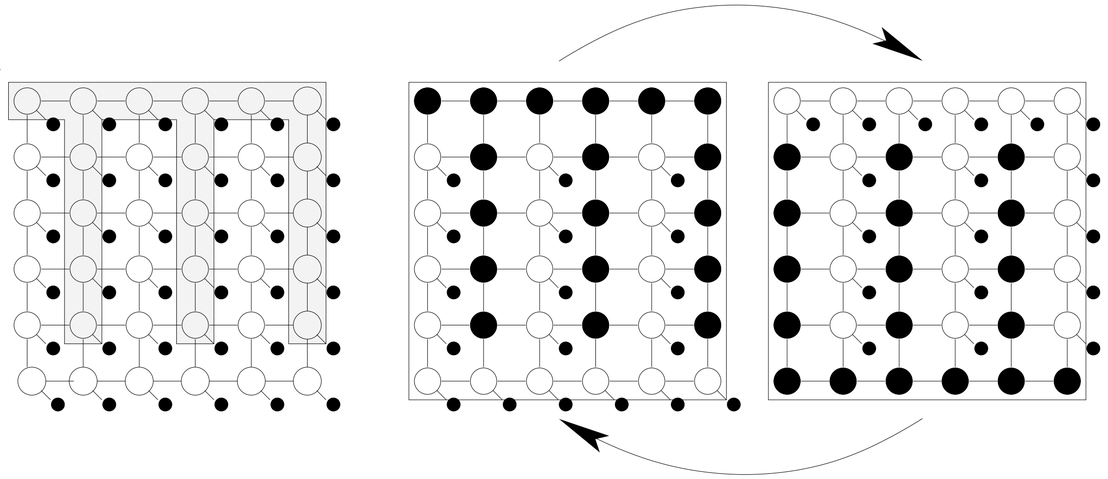
https://arxiv.org/pdf/1207.4149.pdf

https://github.com/alex1770/QUBO-Chimera

HFS

Low Treewidth Subgraphs

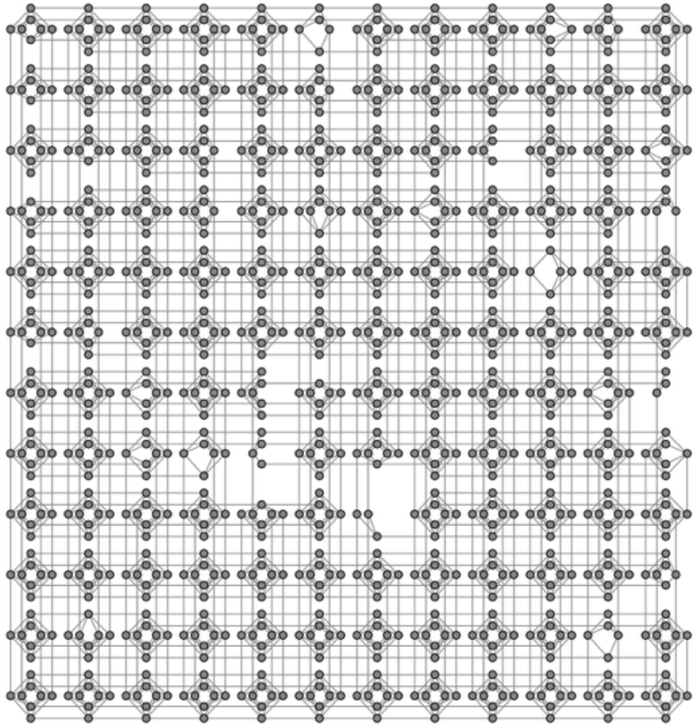
Optimization Loop using DP



UNCLASSIFIED

D-Wave For Optimization

- 10,000 samples @ 5 micro seconds each
- random gauge transform every 100 samples
- use the **best** of all samples
- Takes 3.5 seconds on the QPU



C_{12} DW2X

Open-Source B-QP Tools

Your Problem

SAPI

D-Wave Instance Generator (DWIG)

problem spec.

BQPJSON

glue code

BQPSOLVERS

D-Wave qbsolv

HFS

GUROBI OPTIMIZATION

Google or-tools

Mini Zn

D-Wave

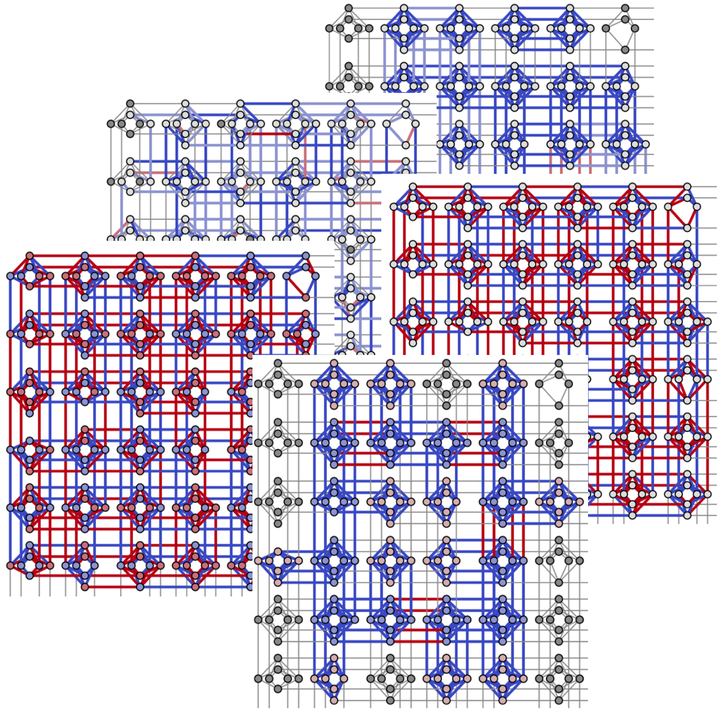
Scott (CCS-7)

Open Source Code

https://github.com/lanl-ansi/dwig

https://github.com/lanl-ansi/bqpjson

D-Wave Instance Generator (DWIG)



BQPSOLVERS

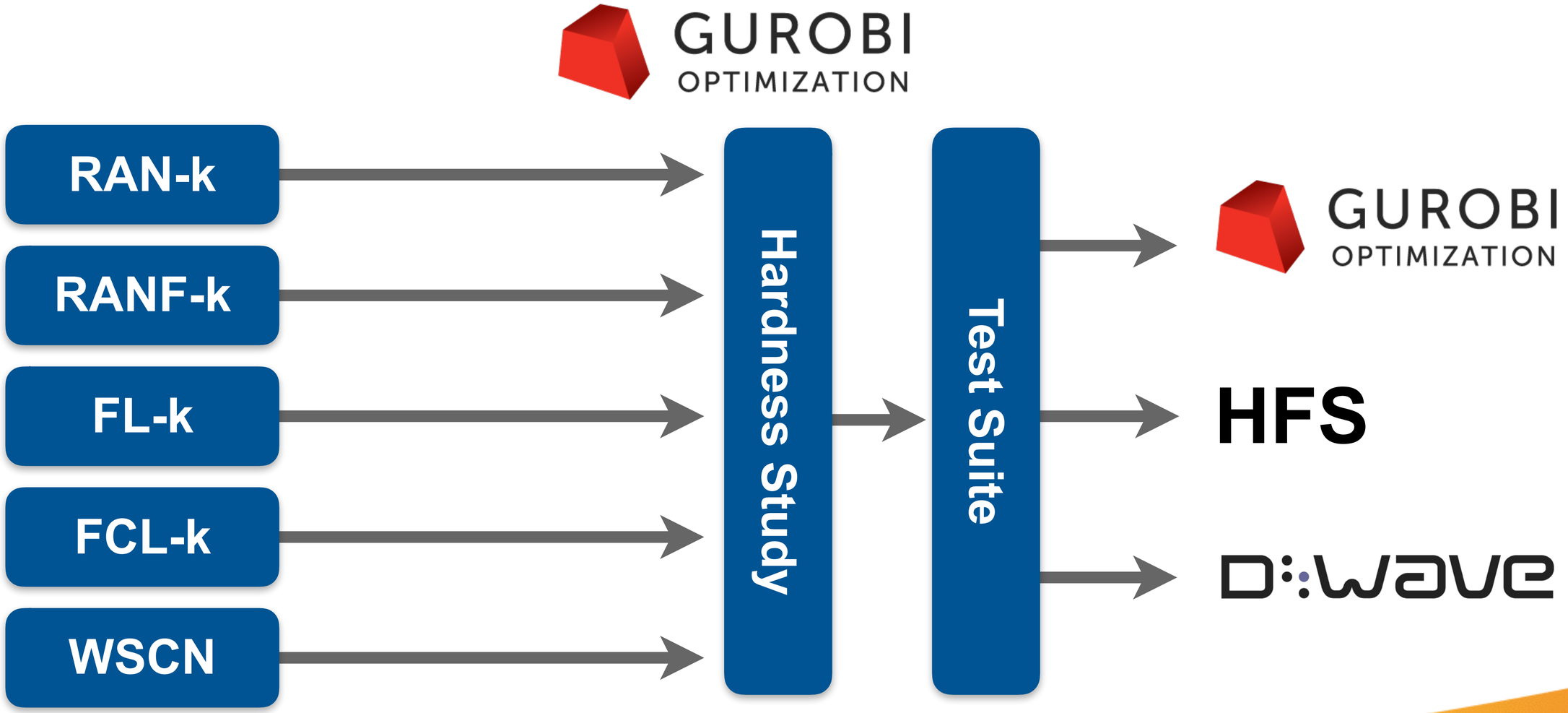
D-Wave

HFS

GUROBI OPTIMIZATION

Time for the Fun Stuff!

Structure of the Benchmark Study

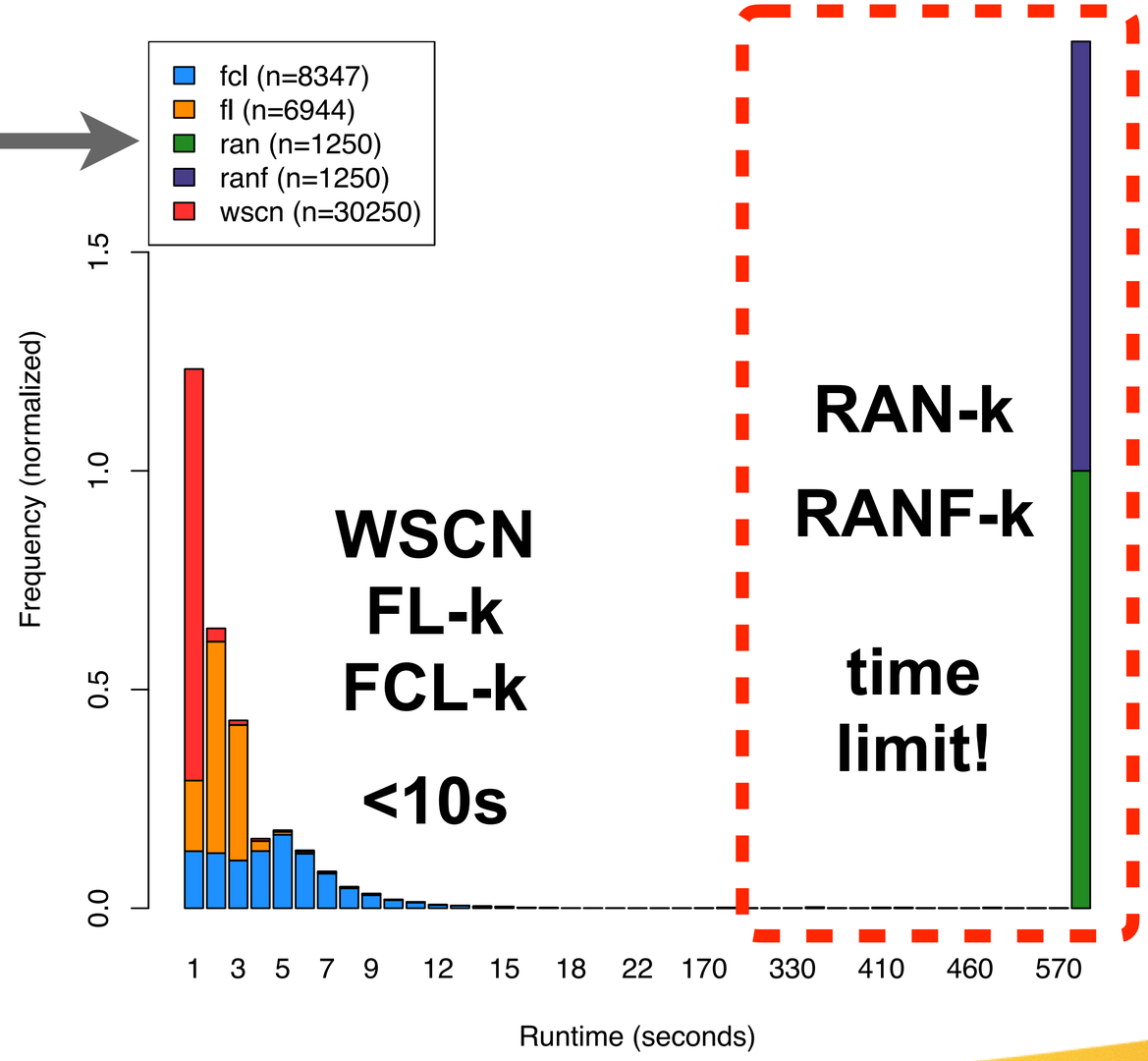


Problem Hardness Test

Runtime Distribution Color Coded by Problem

40,000+ Cases

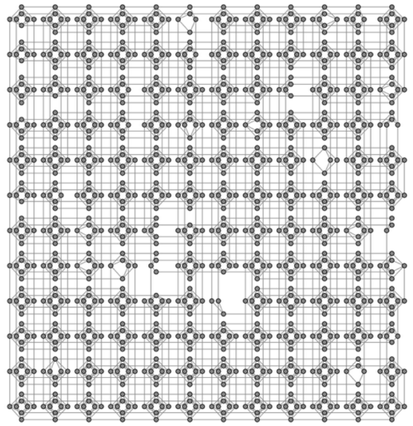
What about the values of k?



GUROBI OPTIMIZATION

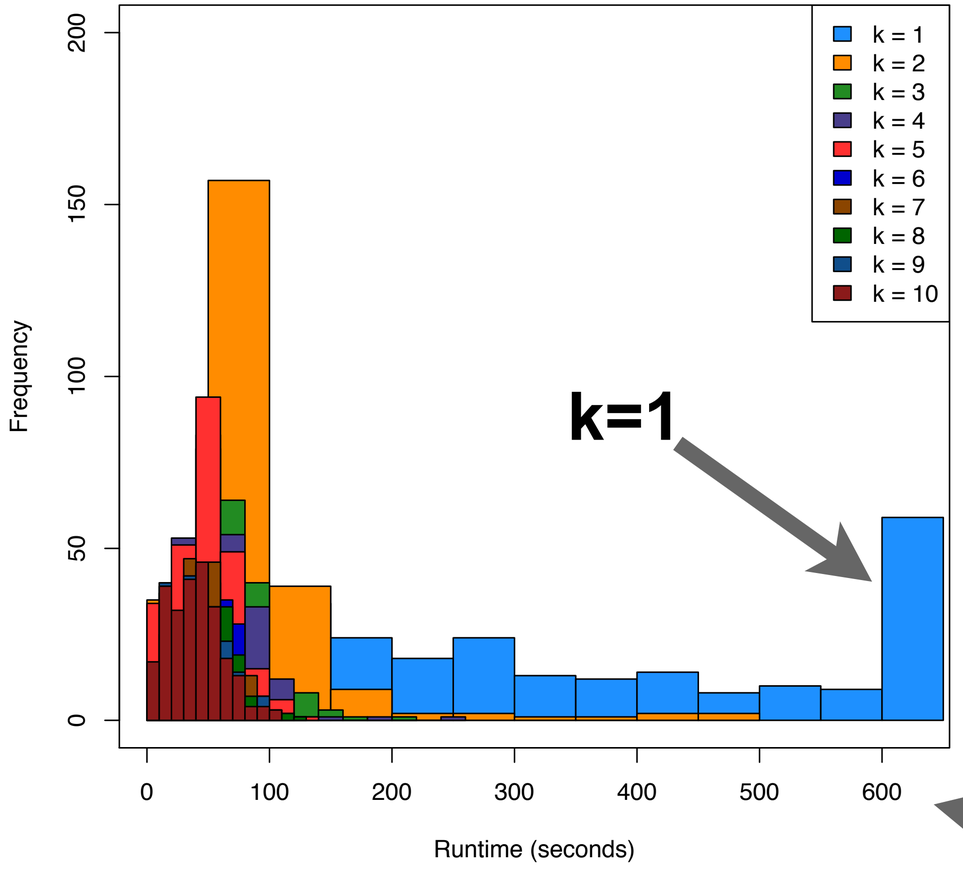
600 second time limit

C_{12} Max Size

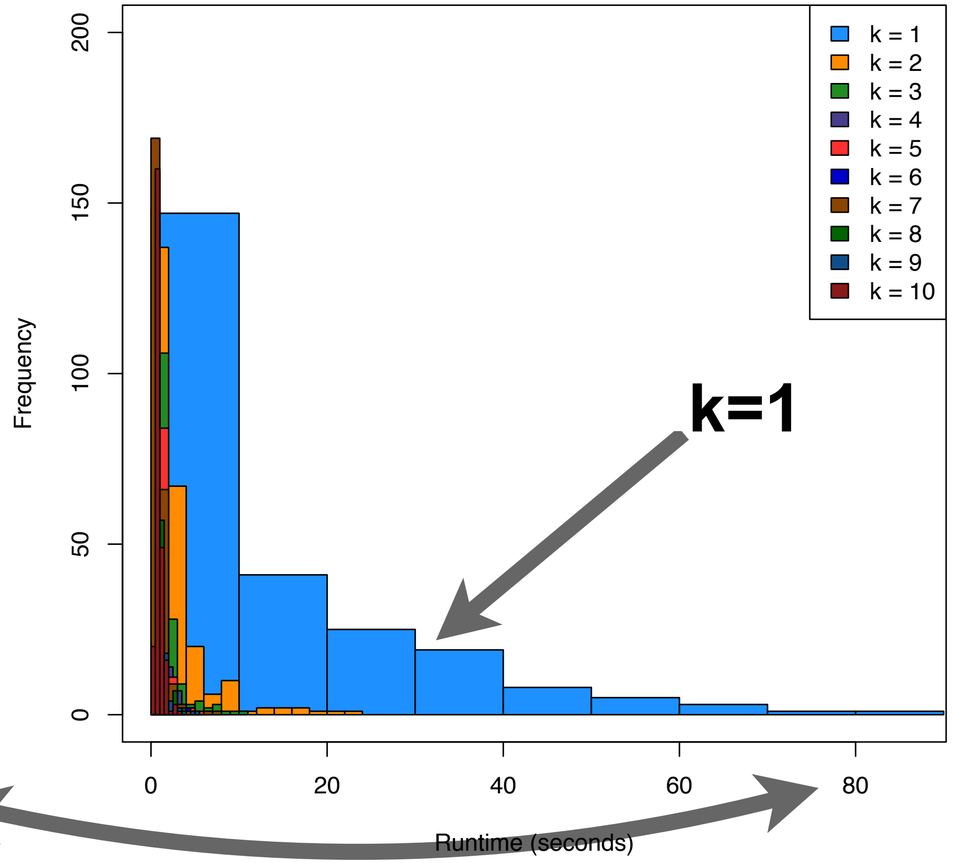


How does Hardness change with K?

RAN-k



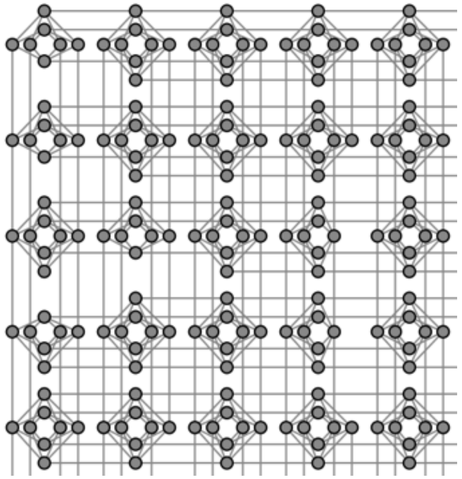
RANF-k



RAN > RANF

GUROBI OPTIMIZATION

optimality proof in 600 sec. or less



C_5

$2^{194} \approx 10^{58}$

These guys know what they are talking about

“Have you tried setting the couplers to -1,1 at random?”
09/2016

Marc
(T-4)

Andrey
(CNLS/T-4)

Sidhant
(T-5)

Focusing

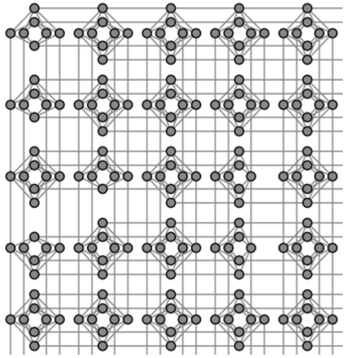
A Detailed Study of RAN-1

HFS

(Similar story for RANF-1, omitted for time)

Detailed Runtime Studies

Part 1

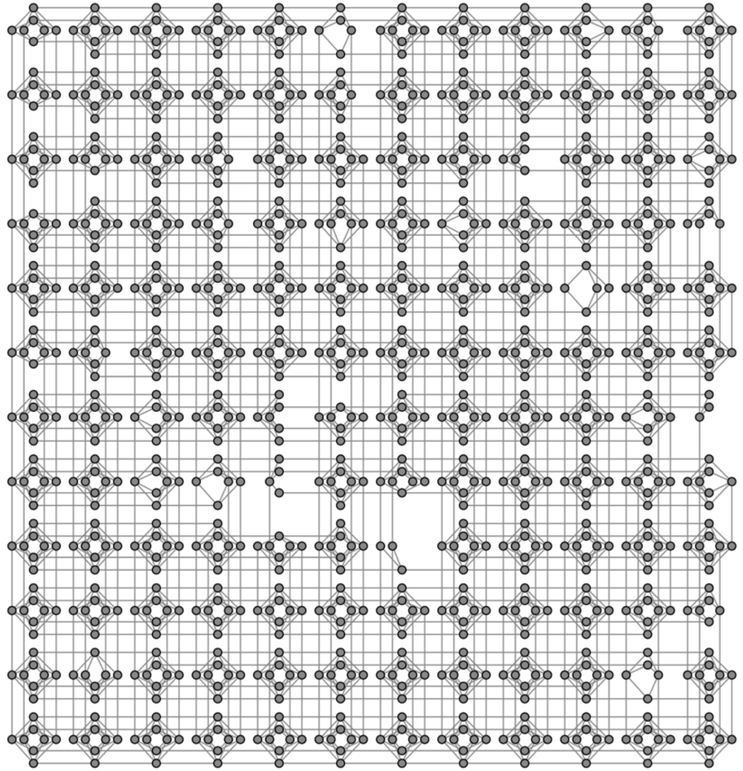


C_5

Quality Validation
(Known Global Optimum)

Wishful Extrapolation

Part 2



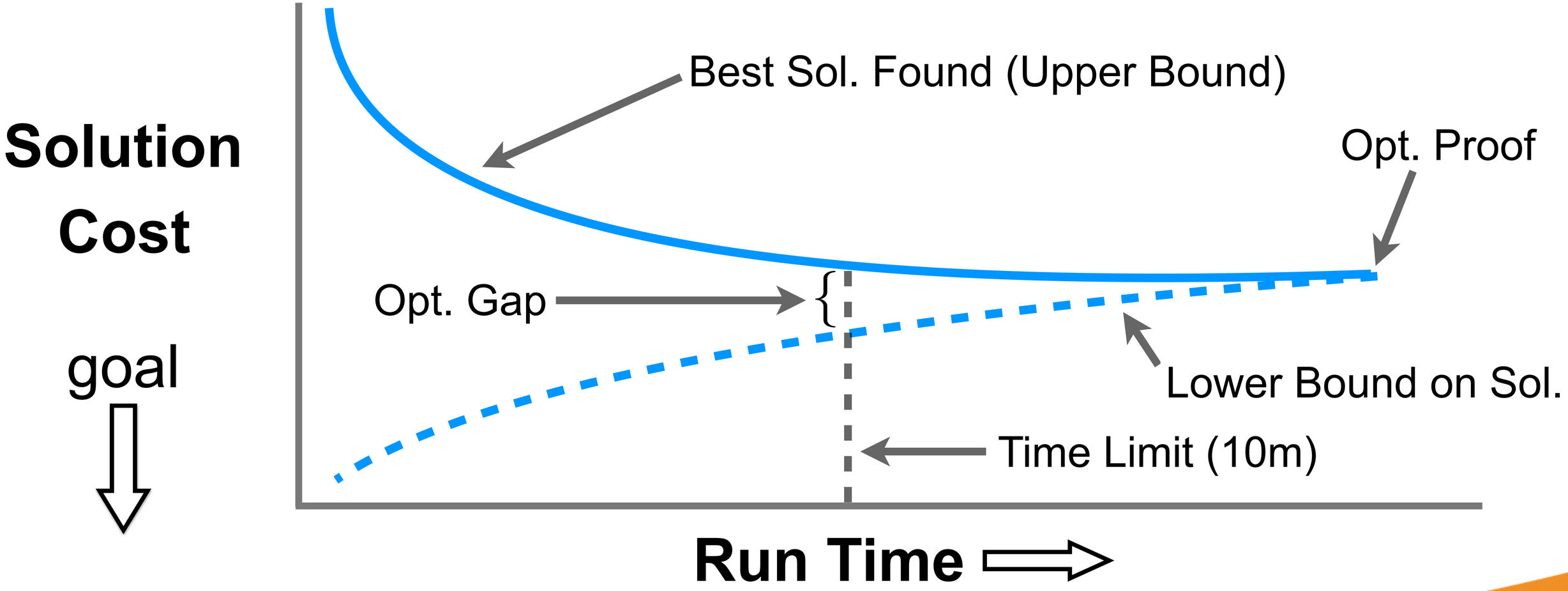
C_{12}

GUROBI OPTIMIZATION

D-WAVE

HFS

Detailed Runtime Studies

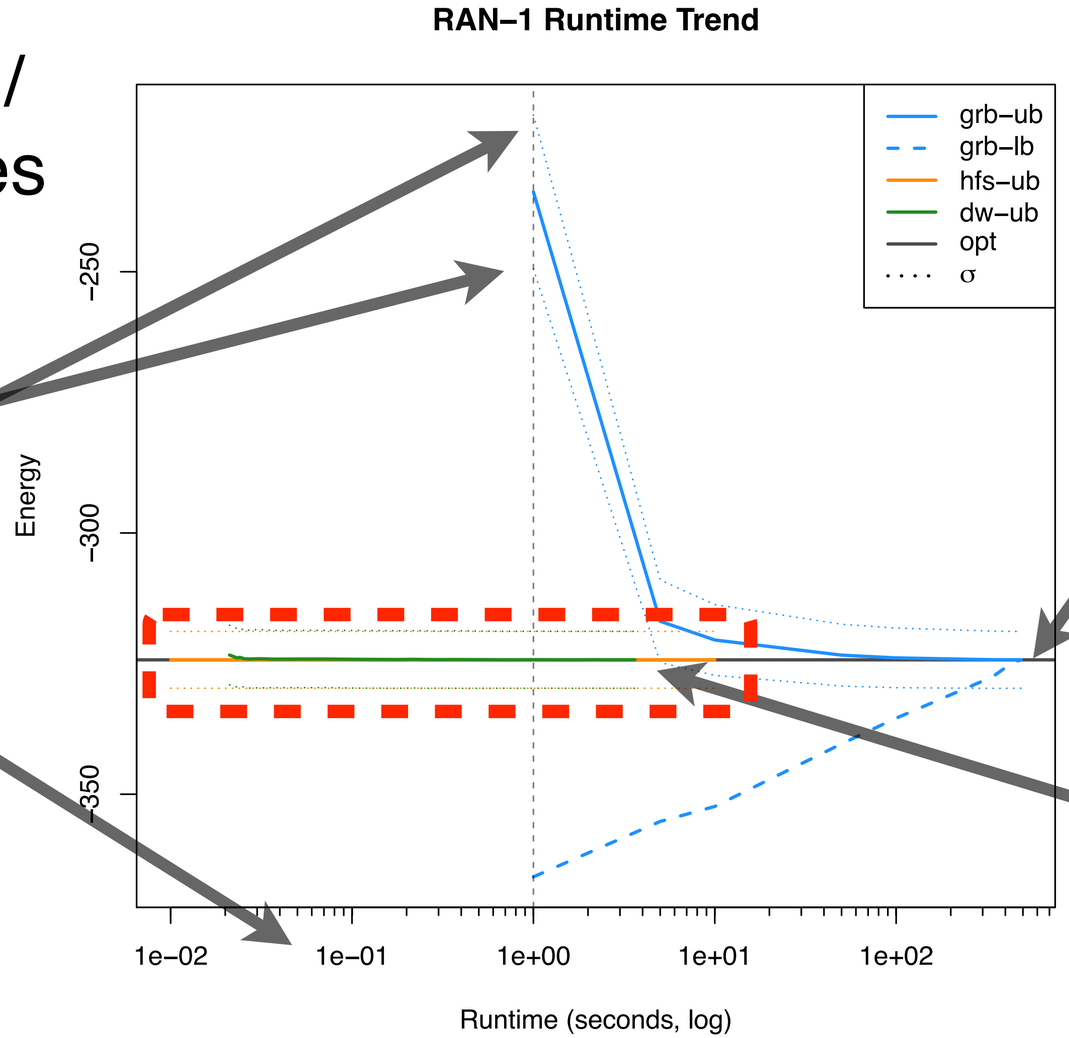


Detailed Runtime Study 1 (RAN-1) C_5

Average Objective / Energy of 200 Cases

Variance in Cases **not** the algorithm

Logarithmic runtime scale



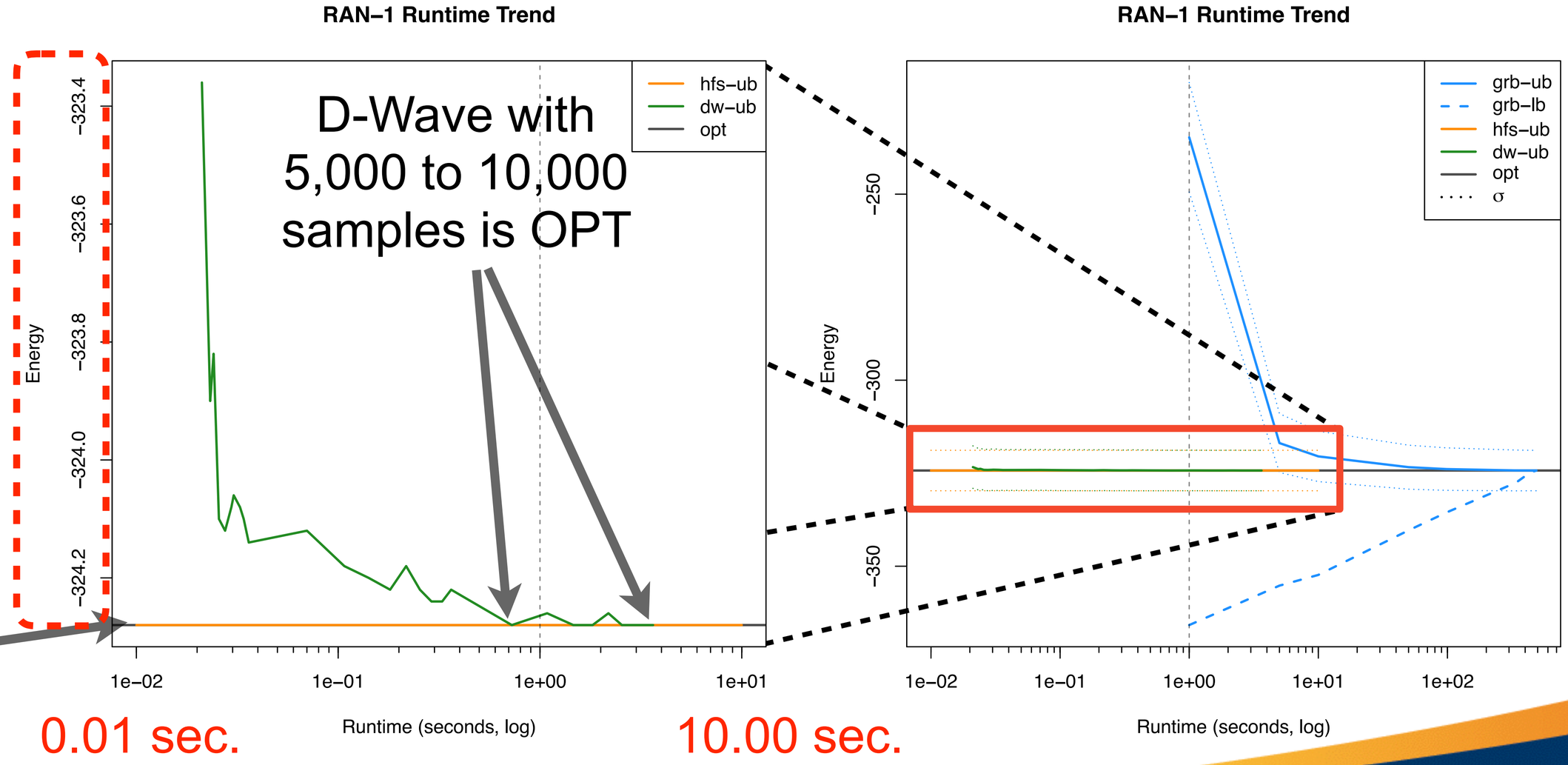
Optimality Proof for all 200 Cases

HFS and D-Wave Indistinguishable

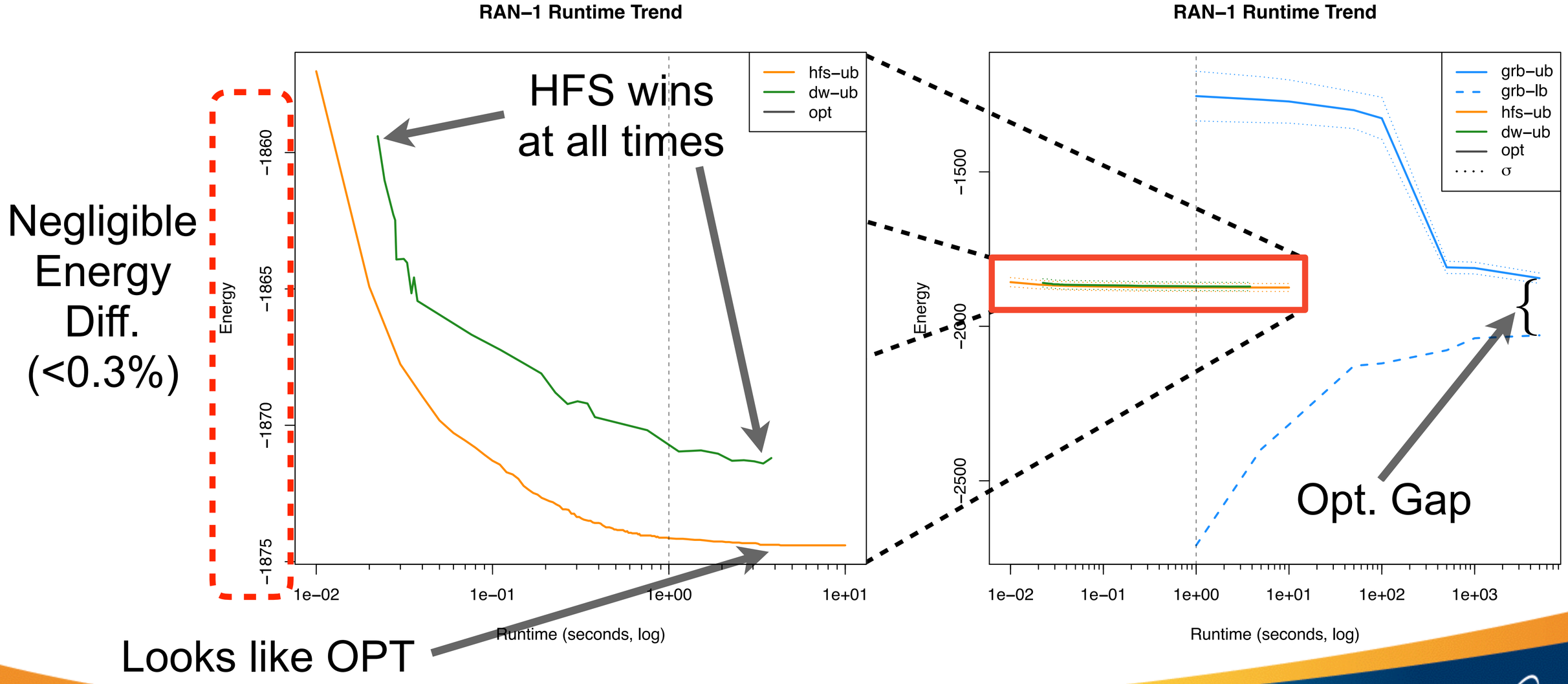
Detailed Runtime Study 1 (RAN-1) C_5

Negligible Energy Diff. (<0.4%)

HFS is always OPT!

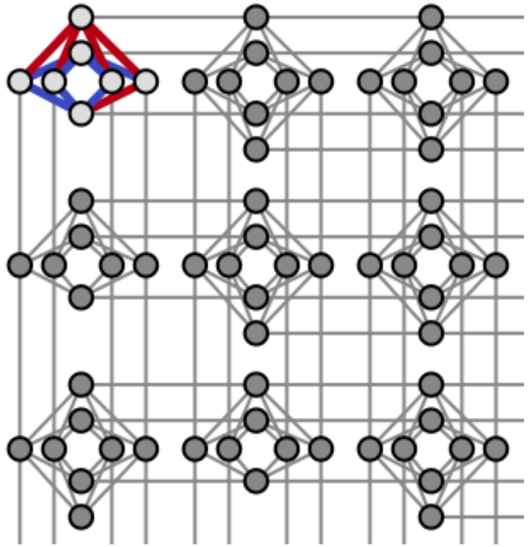


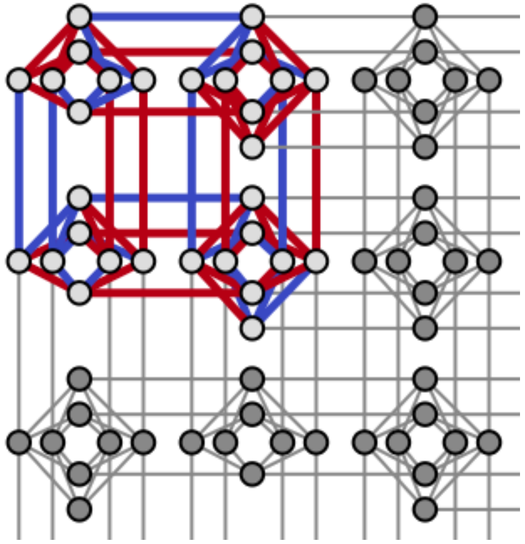
Detailed Runtime Study 2 (RAN-1) c_{12}

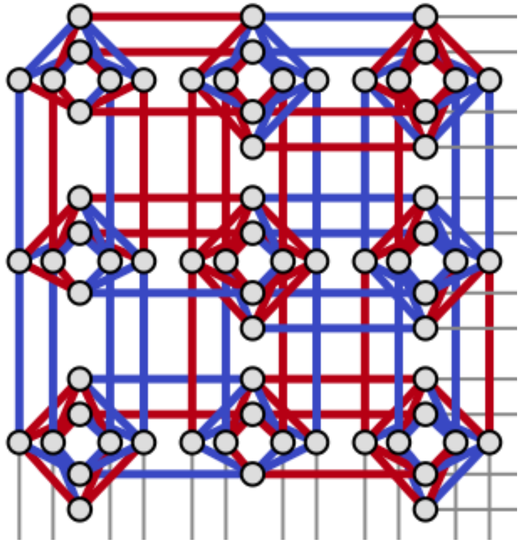


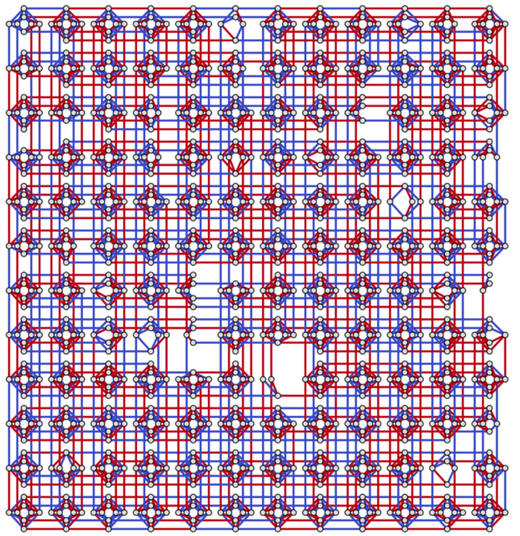
Scalability Study

C_1 C_2 C_3 $\ldots$ C_{12}

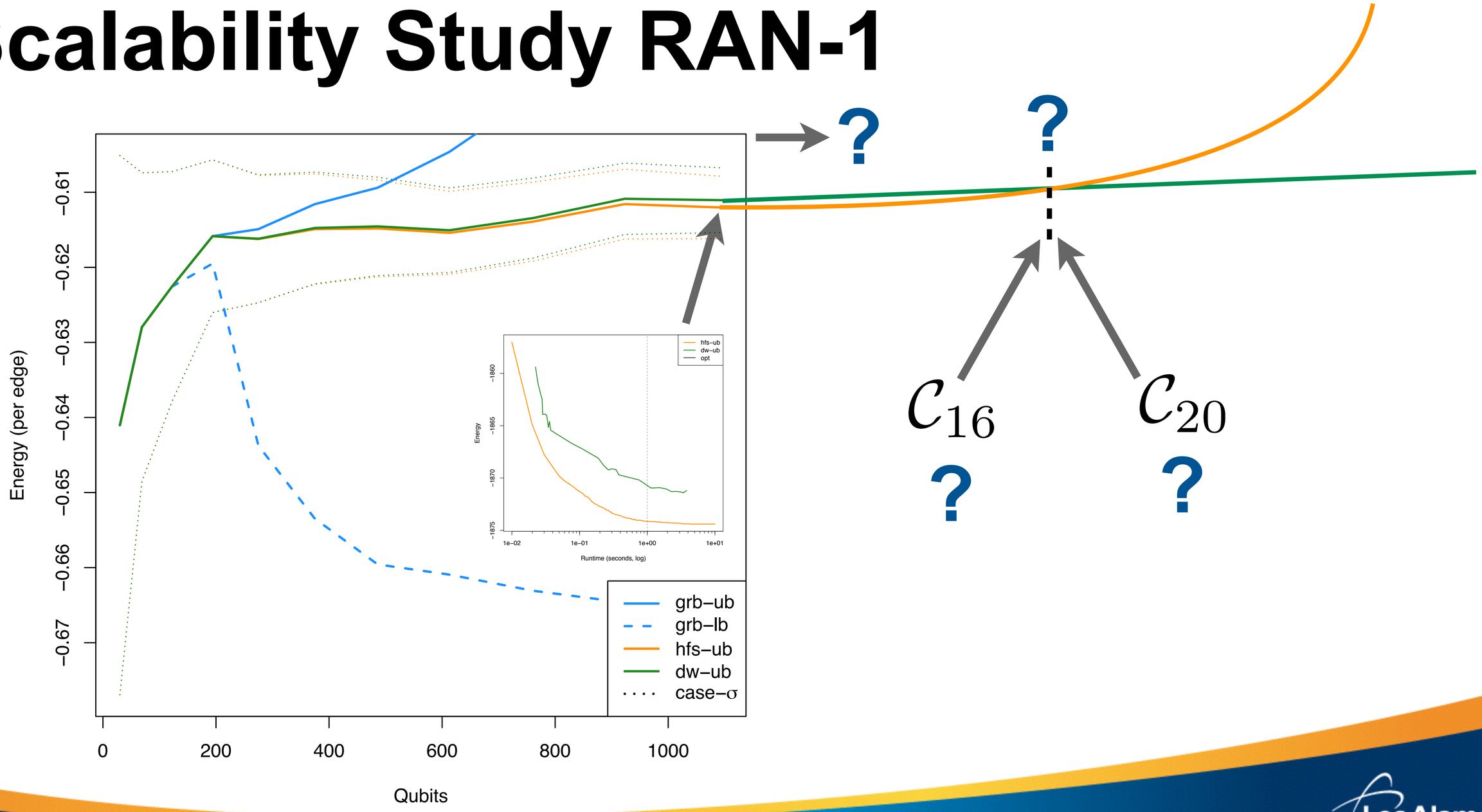








Scalability Study RAN-1



A Word of Caution about RAN-1

- The relative difference in energy between the **best** HFS solution and the **worst** HFS solution is only **<1%**
  - And a similar property is true for the D-Wave!
- This suggests that the RAN problem has many **nearly-equal local minima**
  - This property is not desirable for **benchmarking heuristics** (e.g. SA, TabuSearch, HFS)
- Continued work is needed to design generators of **more challenging test cases!**

Concluding Thoughts

- It seems that all of the popular test cases from the literature are **“easy”**
- Our D-Wave 2X chip is reliable for well-suited optimization applications (e.g. maxcut), but the point where it will overtake classical heuristics is not yet clear (**2000Q anyone?**)
- We still have **more questions**, than answers!

Special Thanks

Ryan
(CCS-7)

Admin of ASC's
Darwin Cluster

Q?

Project Workload

D-Wave Jobs: 60,176

D-Wave CPU Days: 1.16

Darwin Jobs: 1,025,122

Darwin CPU Days: 1,290