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GRID OPTIMIZATION (GO) COMPETITION

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Analysis of GO Competition Challenge 1 Final Event Problem Difficulty

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FERC Technical Conference: Increasing Real-Time and Day-Ahead Market Efficiency and Enhancing Resilience through Improved Software

Thursday, June 25, 2020

Dick O'Neill's role in the Competition

- June 2, 2010 (personal notes)

  Day 1 highlights

  Richard O'Neill (FERC): Rule of thumb: "A one percent improvement saves $1 billion."
- June 26, 2012 (FERC abstracts)

  The Linearized IV ACOPF

  Richard O'Neill, Chief Economic Advisor, Federal Energy Regulatory Commission

  The AC Optimal Power Flow (ACOPF) problem is an important problem because a one percent improvement in dispatch saves roughly 1 to 5 billion dollars per year
- Dec. 2012, Cain, O'Neill & Castillo "History of optimal power flow and formulations" ($6-19 billion savings, p. 5) cited by https://gocompetition.energy.gov/about-competition
- Nov. 18, 2014 ADVANCED BULK POWER SYSTEM OPTIMIZATION TECHNOLOGIES WORKSHOP (Tim Heidel)
  - Dick's slide 4

  Over linearized models could be leaving 10% or more of costs on the table
- June 28, 2017 FERC Conference hosts GRID DATA talks
- June 13, 2018 FERC Conference hosts Competition Workshop (Kory Hedman)
- Nov. 25, 2019 Dick assumes Competition Program Director role.

GO Competition Challenge 1 Final Event

- Concluded with an Outreach Event February 18, 2020, in New Orleans
  - 26 teams took part (including ARPA-E Benchmark)
  - 19 teams funded to participate (18 participated in Final Event)
  - 10 teams shared $3.4 million in prizes (3 winning teams were not funded)

- Datasets
  - GRIDDATA Sources (17 synthetic networks, 2252 scenario instances)
    - PNNL (Henry Huang, Ruisheng Diao, Renke Huang, Ahmad Tbaileh)
    - Wisconsin (Chris DeMarco, Bernie Lesieutre, Scott Greene)
    - Texas A&M (Tom Overby, Adam Birchfield)
  - Industry Sources (3 real networks, 12 scenario instances)
  - Validation
    - PNNL—Ahmad Tbaileh
    - NREL—Venkat Krishnan
    - LANL—Carleton Coffrin (Benchmark and Hardness assessment, select 340 syn)

Highlights

- Only 8 teams produced the 704 best results
  - LLNL accounted for 408 (58%)
    Gold standard for reliability, robustness, and accuracy
  - Lehigh accounted for 141 (20%)
  - BAT accounted for 84 not funded
  - GaTech (Sun) 36
  - Gravityx 24 not funded
  - GERS USA 4
  - Mississippi State 1 not funded
  - OK Reactors 1 not funded
- Only 3 teams had no “failures” for any scenario
  - LLNL (D1, D2 place: syn 1,1; ind 1,1)
  - University of Colorado Boulder (syn 7,8; ind 2,4)
  - ARPA-E benchmark (syn 10,11; ind 7,9)
- Georgia Tech had no failures in Divisions 1 & 4
  3rd place

- 1/4 of synthetic scenarios submissions failed
- 2/3 of industry scenarios submissions failed
- Failed=slack score (many possible reasons)
- Were the datasets too hard?

Measuring problem difficulty

- Measuring the gap between upper and lower bound is a conventional way of measuring quality. Also, a problem with a small gap with the given run time is presumed easier than a problem with a larger gap in the same time.
- We don't know the bounds here, but we have a range of results.
- Our gap percent method considers the % difference between
  - The best objective value (score) by any team for a given scenario instance
  - The second-best objective value by any team

    $Gap\% = O_2/O_1 - 1$
- The size of the gap is a measure of difficulty (*a posteriori*)
  - Small gap: neither team had trouble getting nearly the same answer
  - Large gap: the 2nd place team is having more difficulty than the 1st place team
- Gap% method based on multiple independent calculations
- A "Wisdom of the Crowd" technique
  - "noise cancellation" (the larger the set, the less likely a bad result)
  - Dates from Aristotle

Division 1 (real-time, 10-minute code1 time limit)

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Synthetic Network	2	3	6	8	9	12	13	14	20	25	30	70	75	82	83	86	88	Totals
<0.01% exceedingly easy	0	6	5	0	0	1	2	0	3	0	1	3	3	6	2	1	1	34
>0.01% <0.1% very easy	1	9	15	17	0	4	11	9	17	2	16	14	13	10	8	5	11	162
>0.1% <0.5% moderately easy	17	1	0	3	3	15	7	11	0	2	2	3	4	4	10	14	8	104
>0.5% <1.0% easy	1	4	0	0	3	0	0	0	0	15	1	0	0	0	0	0	0	24
>1.0% <2.0% difficult	1	0	0	0	10	0	0	0	0	1	0	0	0	0	0	0	0	12
>2.0% <4.0% somewhat hard	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	4
>4.0% exceedingly hard	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
min teams under threshold per scenario	0	1	5	1	0	3	3	3	3	0	1	2	3	3	3	3	2	
count scenarios with min teams under thresh.	1	4	1	3	14	12	20	1	5	1	2	1	1	4	1	5	1	
max teams under threshold per scenario	7	13	7	6	2	4	3	6	6	3	3	7	5	7	7	6	5	
count scenarios with max teams under thresh.	1	1	2	2	2	8	20	2	1	1	12	3	14	1	3	2	4	
max gap	1.075%	0.787%	0.042%	0.180%	3.69%	0.136%	0.135%	0.215%	0.034%	1.061%	0.965%	0.134%	0.163%	0.220%	0.403%	0.314%	0.165%	
min gap	0.017%	0.000%	0.001%	0.010%	0.22%	0.007%	0.000%	0.066%	0.001%	0.034%	0.004%	0.004%	0.0060%	0.000%	0.001%	0.008%	0.006%	
geomean gap	0.360%	0.162%	0.027%	0.054%	2.03%	0.105%	0.004%	0.116%	0.021%	1.058%	0.143%	0.049%	0.0450%	0.065%	0.416%	0.111%	0.085%	
dynamic range (max gap / min gap)	64	40,260	31	18	16	19	394	3	25	32	274	30	27	2,504	350	42	26	
geomean slacks (20% of total)	3	2	4	7	6	5	6	7	7	11	9	2	4	4	4	4	5	90
scenario slacks (25% of total)	93	67	100	148	124	121	167	152	174	224	209	84	123	101	94	115	142	2238
buses	500	793	2000	3022	4918	~9000	10,000	10,480	~19,000	~24,465	30,000	2312	2742	~4000	4020	4619	~4837	
Data Provider	TAMU	PNNL	TAMU	PNNL	PNNL	Wisc.	TAMU	Wisc.	Wisc.	Wisc.	TAMU	PNNL	Wisc.	Wisc.	Wisc.	Wisc.	Wisc.	

Industry Network	40	41	42	Totals
<0.01% exceedingly easy	0	0	2	2
>0.01% <0.1% very easy	1	0	2	3
>0.1% <0.5% moderately easy	2	0	0	2
>0.5% <1.0% easy	0	1	0	1
>1.0% <2.0% difficult	0	2	0	2
>2.0% <4.0% somewhat hard	0	0	0	0
>4.0% exceedingly hard	1	1	0	2
min teams under threshold per scenario	0	0	1	
count scenarios with min teams under thresh.	1	3	4	
max teams under threshold per scenario	1	1	1	
count scenarios with max teams under thresh.	3	1	4	
max gap	10.15%	12.94%	0.02%	
min gap	0.08%	0.64%	0.01%	
geomean gap	2.32%	3.78%	0.01%	
dynamic range (max gap / min gap)	126	20	2	
geomean slacks (65% of total)	15	19	17	51
scenario slacks (67% of total)	63	76	70	209

Starting point information given

Division 2 (off-line, 45-minute code1 time limit)

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<0.01% exceedingly easy	0	6	5	0	0	1	2	0	3	0	1	3	3	6	2	1	1	34
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>0.5% <1.0% easy	1	4	0	0	3	0	0	0	0	15	1	0	0	0	0	0	0	24
>1.0% <2.0% difficult	1	0	0	0	10	0	0	0	0	1	0	0	0	0	0	0	0	12
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min teams under threshold per scenario	0	1	5	1	0	3	3	3	3	0	1	2	3	3	3	3	2	
count scenarios with min teams under thresh.	1	4	1	3	14	12	20	1	5	1	2	1	1	4	1	5	1	
max teams under threshold per scenario	7	13	7	6	2	4	3	6	6	3	3	7	5	7	7	6	5	
count scenarios with max teams under thresh.	1	1	2	2	2	8	20	2	1	1	12	3	14	1	3	2	4	
max gap	1.075%	0.787%	0.042%	0.180%	3.69%	0.136%	0.135%	0.215%	0.034%	1.061%	0.965%	0.134%	0.163%	0.220%	0.403%	0.314%	0.165%	
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scenario slacks (24% of total)	93	67	100	148	124	121	167	152	174	224	209	84	123	101	94	115	142	2238
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max teams under threshold per scenario	1	1	1	
count scenarios with max teams under thresh.	3	1	4	
max gap	10.15%	12.94%	0.02%	
min gap	0.08%	0.64%	0.01%	
geomean gap	2.32%	3.78%	0.01%	
dynamic range (max gap / min gap)	126	20	2	
geomean slacks (65% of total)	15	19	17	51
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No starting point information given

Observations

- Network with smallest geomean Gap% has least slack scores
- Network with largest geomean Gap% NOT the one with the most slacks
- The range of difficulty seems reasonable.
- Failure rate is associated with larger problems, not harder ones, and poorly designed codes.
- Problems observed
  - Time management, failure to produce intermediate results
    - Colorado & Benchmark focused on always getting a valid, not best, solution.
  - Memory management
  - Lack of MPI experience
  - Poorly debugged code resulting in segmentation violations, infeasible results, results larger than slack score, failures to parse input data, NaNs
  - Non-robust algorithms that gave up too easily or too focused on base case
  - Poor use of starting information

Selection of Final Event Datasets

- Based on a “Hardness” index developed by Carleton Coffrin (LANL)
- Hardness index is a product of 3 values
  - Relative cost (C^r), the difference of DC-SCOP and AC-OPF generation cost normalized by the AC-OPF cost value
  - Relative penalty (P^r), the AC penalty value divided by the cost,
  - $\log_{10}$ of a relative upper bound penalty (P^{ubr}), the AC penalty upper bound divided by the cost

$$H = C^r P^r \log_{10} P^{ubr}$$

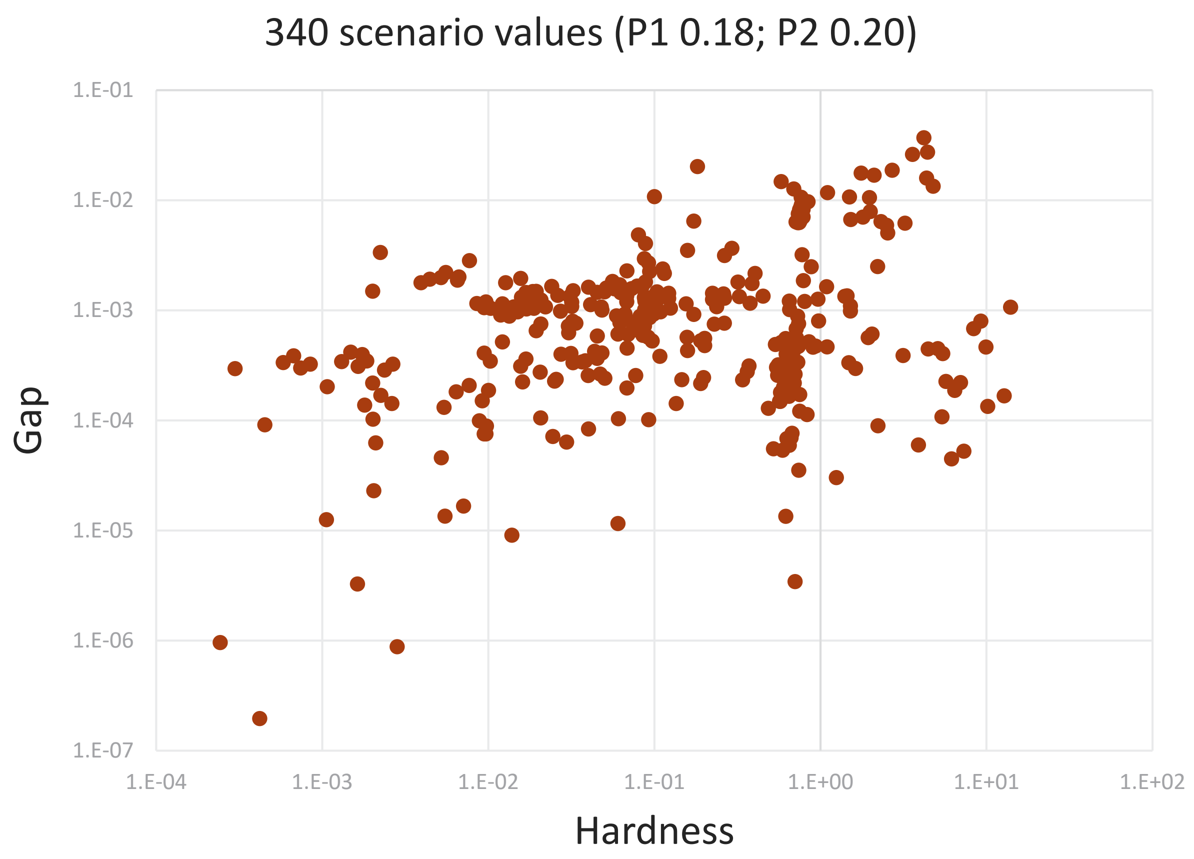
- Calculated using Coffrin’s benchmark code on the Division 2 datasets
  - Metric breaks down completely on the larger cases (Networks 20, 25, and 30)
  - Partial break down on some others (8 from Network 75 & 6 from Network 82)
  - Selections made using approximations
- Final selection aimed for a distribution of Hardness values

Distribution of Gap% and Hardness values

value greater than	but less than	Gap% count	Hardness count
0	0.001	6	8
0.001	0.01	28	42
0.01	0.1	162	110
0.1	1	128	132
1	10	16	45
10	100	0	3
maximum gap%	minimum gap%	total	
3.69	1.95E-05	340	

The gap% distribution is comparable to the Hardness distribution.
The Pearson coefficient between the two distributions is a strong 0.94.

A different perspective at the scenario level…



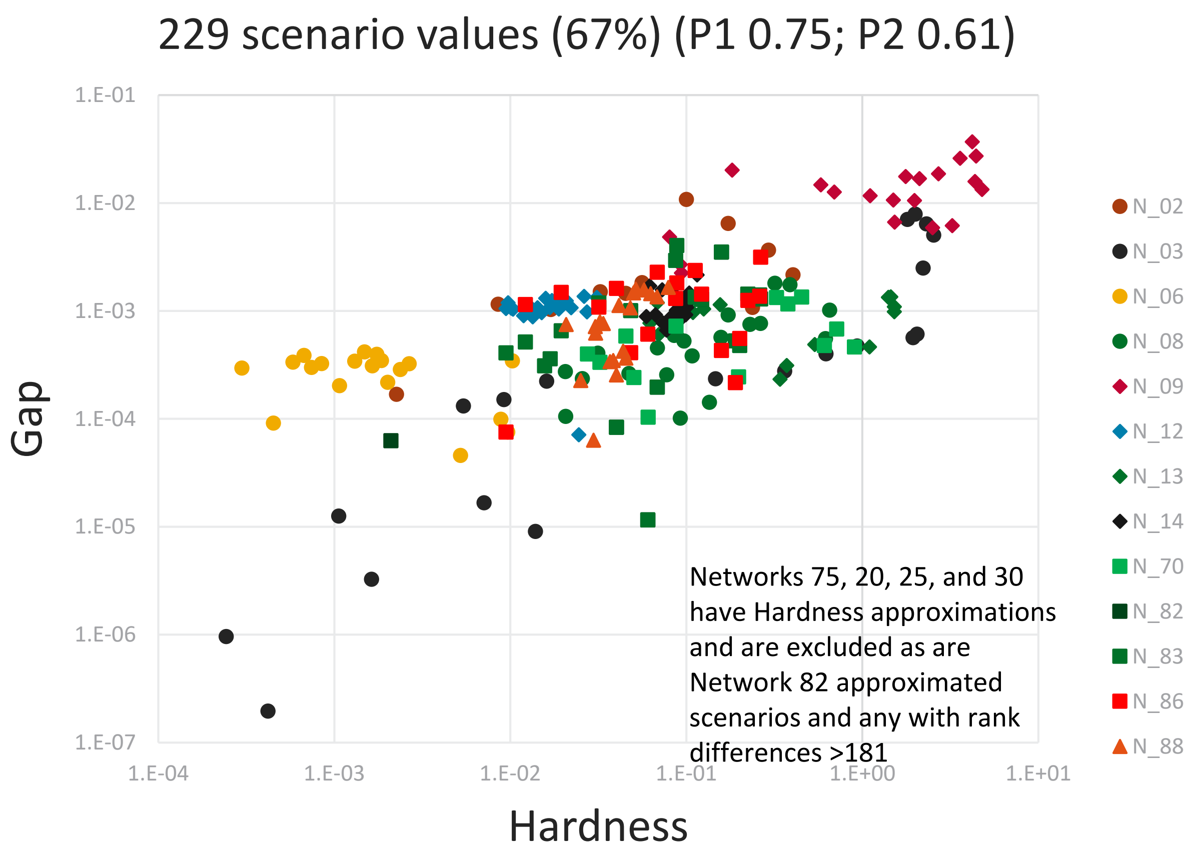
Note log-log scale

Binning

- Assigning a bin number to each value (binning) can smooth variance
  - Sort the list of values into ascending order and assign bins according to rank
  - Sort again the absolute value of the difference between bins of each set to find “problem” values.
  - Exclude “problem values” and recalculate Pearson

- We use two types of binning
  - Global, where the Pearson’s correlation coefficient considers the two sets (Gap% and H) of all values sorted and ranked: P2
  - Local, where the 20 values belonging to a given network are sorted and ranked: P3
  - P1 is when no binning is used, and Pearson’s considers the two sets of Gap% and H values.

Pruning


229 scenario values (67%) (P1 0.75; P2 0.61)
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
1.E-07
Gap
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
Hardness
N_02
N_03
N_06
N_08
N_09
N_12
N_13
N_14
N_70
N_82
N_83
N_86
N_88
Networks 75, 20, 25, and 30 have Hardness approximations and are excluded as are Network 82 approximated scenarios and any with rank differences >181

Texas datasets Gap% vs. Hardness

Texas 500	Network_02			Texas 2000	Network_06			Texas 10,000	Network_13			Texas 30,000	Network_30		
scenarios	P1	P2	P3	scenarios	P1	P2	P3	scenarios	P1	P2	P3	scenarios	P1	P2	P3
20	0.24	0.32	0.26	20	-0.47	-0.42	-0.27	20	-0.02	-0.22	-0.07	20	0.37	0.65	0.56
19	0.31	0.39	0.38	19	-0.37	-0.28	-0.19	19	0.05	-0.07	0.02	19	0.37	0.62	0.67
18	0.32	0.48	0.51	18	-0.30	-0.16	-0.08	18	0.14	0.01	0.09	18	0.37	0.76	0.82
17	0.33	0.53	0.59	17	-0.20	-0.01	0.05	17	0.24	0.07	0.16	17	0.36	0.76	0.82
16	0.33	0.58	0.67	16	-0.18	0.04	0.13	16	0.28	0.14	0.22	16	0.36	0.76	0.83
15	0.32	0.58	0.71	15	0.22	0.33	0.32	15	0.36	0.26	0.31	15	0.35	0.77	0.87
14	0.31	0.58	0.73	14	0.26	0.35	0.36	14	0.45	0.31	0.36	14	0.34	0.78	0.93
13	0.30	0.64	0.78	13	0.30	0.44	0.44	13	0.46	0.34	0.38	13	0.33	0.76	0.93
12	0.28	0.78	0.85	12	0.34	0.44	0.47	12	0.56	0.41	0.45	12	0.64	0.84	0.94
11	0.26	0.78	0.87	11	0.36	0.51	0.47	11	0.67	0.48	0.52	11	0.62	0.83	0.95
10	0.49	0.82	0.89	10	0.41	0.58	0.55	10	0.66	0.47	0.53	10	0.60	0.81	0.95
9	0.74	0.80	0.90	9	0.47	0.69	0.65	9	0.76	0.52	0.61	9	0.57	0.79	0.94
8	0.74	0.80	0.92	8	0.47	0.70	0.71	8	0.87	0.61	0.67	8	0.68	0.84	0.94
7	0.74	0.88	0.98	7	0.47	0.79	0.81	7	0.91	0.71	0.75	7	0.76	0.92	0.97
6	0.73	0.90	0.98	6	0.54	0.81	0.90	6	0.90	0.71	0.76	6	0.76	0.93	0.99
5	0.70	0.95	0.98	5	0.63	0.94	0.97	5	0.91	0.78	0.76	5	0.73	0.91	0.99

20 approximate H

Scenarios Needed for Pearson coeff.

		>0.5	>0.6	>0.7	>0.8	>0.9	sum
Network_02	Texas 500	18	16	15	12	9	70
Network_06	Texas 2000	11	9	8	7	6	41
Network_13	Texas 10,000	12	11	9	8	7	47
Network_30	Texas 30,000	20	20	18	18	14	90

PNNL datasets Gap% vs. Hardness

PNNL 793 scenarios	Network_03 P1	P2	P3
20	0.75	0.90	0.93
19	0.75	0.92	0.95
18	0.77	0.94	0.97
17	0.77	0.95	0.98
16	0.70	0.94	0.98
15	0.67	0.94	0.98
14	0.76	0.94	0.98
13	0.76	0.95	0.99
12	0.76	0.94	0.99
11	0.87	0.96	0.99
10	0.89	0.95	0.99
9	0.90	0.95	0.99
8	0.90	0.94	0.99
7	0.89	0.93	1.00
6	0.90	0.98	1.00
5	0.84	0.98	1.00

PNNL 2312 scenarios	Network_70 P1	P2	P3
20	-0.46	-0.33	-0.42
19	-0.40	-0.29	-0.33
18	-0.33	-0.18	-0.22
17	-0.27	-0.09	-0.10
16	-0.24	0.04	0.04
15	-0.24	0.07	0.09
14	-0.12	0.24	0.29
13	0.30	0.42	0.46
12	0.47	0.49	0.53
11	0.48	0.54	0.59
10	0.60	0.59	0.62
9	0.62	0.58	0.61
8	0.20	0.71	0.69
7	0.22	0.81	0.80
6	0.85	0.91	0.91
5	0.90	0.90	0.91

PNNL 3022 scenarios	Network_08 P1	P2	P3
20	0.59	0.65	0.74
19	0.59	0.77	0.80
18	0.59	0.82	0.85
17	0.74	0.86	0.89
16	0.74	0.87	0.91
15	0.73	0.87	0.93
14	0.72	0.89	0.94
13	0.71	0.91	0.96
12	0.75	0.92	0.96
11	0.77	0.92	0.97
10	0.77	0.93	0.98
9	0.95	0.94	0.99
8	0.95	0.95	1.00
7	0.96	0.97	1.00
6	0.99	0.99	1.00
5	0.98	0.99	1.00

PNNL 4918 scenarios	Network_09 P1	P2	P3
20	0.57	0.56	0.55
19	0.65	0.58	0.66
18	0.70	0.66	0.72
17	0.78	0.68	0.77
16	0.83	0.76	0.85
15	0.86	0.82	0.89
14	0.93	0.83	0.92
13	0.93	0.84	0.93
12	0.94	0.84	0.96
11	0.96	0.89	0.97
10	0.97	0.87	0.96
9	0.99	0.88	0.98
8	0.99	0.87	0.98
7	0.98	0.85	0.97
6	0.99	0.83	0.97
5	1.00	0.89	0.98

Scenarios Needed for Pearson coeff.

	Pearson	>0.5	>0.6	>0.7	>0.8	>0.9	Sum
Network_03	PNNL 793	20	20	20	20	20	100
Network_70	PNNL 2312	12	10	8	7	6	43
Network_08	PNNL 3022	20	20	20	19	16	95
Network_09	PNNL 4918	20	19	18	16	14	87

Wisconsin datasets (1) Gap% vs. Hardness

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WI 2742	Network_75		
Scen.	P1	P2	P3
20	-0.06	-0.04	0.05
19	0.02	0.08	0.19
18	0.03	0.14	0.29
17	0.11	0.23	0.36
16	0.18	0.35	0.45
15	0.46	0.49	0.57
14	0.79	0.66	0.74
13	0.82	0.72	0.80
12	0.84	0.77	0.88
11	0.90	0.87	0.92
10	0.94	0.95	0.97
9	0.99	0.97	0.98
8	0.99	0.98	1.00
7	0.99	0.98	1.00
6	0.98	0.98	1.00
5	0.98	0.98	1.00
	8 approximate H		

WI 3970+	Network_82		
Scen.	P1	P2	P3
20	-0.30	-0.25	0.20
19	-0.27	0.00	0.30
18	0.03	0.14	0.29
17	0.11	0.23	0.36
16	0.18	0.35	0.45
15	-0.07	0.21	0.60
14	-0.09	0.20	0.64
13	-0.07	0.22	0.68
12	-0.09	0.24	0.73
11	0.56	0.77	0.80
10	0.59	0.79	0.82
9	0.51	0.79	0.81
8	0.99	0.98	1.00
7	0.54	0.90	0.91
6	0.53	0.94	0.93
5	0.91	0.93	0.94
	6 approximate H		

WI 4020	Network_83		
Scen.	P1	P2	P3
20	0.27	0.51	0.55
19	0.33	0.53	0.61
18	0.43	0.54	0.63
17	0.42	0.59	0.67
16	0.48	0.64	0.71
15	0.57	0.66	0.74
14	0.57	0.74	0.80
13	0.62	0.74	0.82
12	0.64	0.78	0.85
11	0.62	0.79	0.86
10	0.60	0.91	0.92
9	0.58	0.91	0.93
8	0.53	0.90	0.93
7	0.83	0.94	0.96
6	0.86	0.95	0.97
5	0.90	0.97	0.98

WI 4619	Network_86		
Scen.	P1	P2	P3
20	0.14	0.09	0.08
19	0.23	0.23	0.17
18	0.29	0.31	0.27
17	0.39	0.39	0.36
16	0.48	0.50	0.46
15	0.56	0.53	0.54
14	0.58	0.58	0.58
13	0.60	0.64	0.64
12	0.77	0.67	0.73
11	0.82	0.69	0.76
10	0.86	0.74	0.82
9	0.89	0.73	0.84
8	0.93	0.86	0.91
7	0.93	0.87	0.94
6	0.96	0.88	0.97
5	0.96	0.88	0.99

WI 4837	Network_88		
Scen.	P1	P2	P3
20	0.74	0.71	0.72
19	0.78	0.78	0.77
18	0.80	0.81	0.80
17	0.82	0.84	0.83
16	0.83	0.85	0.86
15	0.84	0.87	0.88
14	0.85	0.90	0.90
13	0.86	0.91	0.92
12	0.87	0.91	0.93
11	0.87	0.91	0.95
10	0.87	0.92	0.96
9	0.89	0.92	0.96
8	0.91	0.93	0.97
7	0.91	0.97	0.98
6	0.90	0.97	0.99
5	0.93	0.97	0.99

Wisconsin datasets (2) Gap% vs. Hardness

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WI 8718	Network_12			WI 10,480	Network_14			WI 18,877+	Network_20			WI 24,464	Network_25		
scenarios	P1	P2	P3	scenarios	P1	P2	P3	scenarios	P1	P2	P3	scenarios	P1	P2	P3
20	-0.01	-0.07	0.25	20	0.30	0.26	0.30	20	-0.16	-0.10	-0.09	20	0.32	0.47	0.44
19	0.47	0.44	0.39	19	0.50	0.45	0.47	19	-0.07	-0.01	0.01	19	0.51	0.50	0.63
18	0.62	0.58	0.54	18	0.62	0.61	0.61	18	0.06	0.11	0.15	18	0.62	0.51	0.72
17	0.69	0.67	0.64	17	0.70	0.75	0.72	17	0.17	0.22	0.25	17	0.66	0.52	0.81
16	0.70	0.70	0.67	16	0.72	0.78	0.75	16	0.35	0.36	0.34	16	0.66	0.52	0.84
15	0.72	0.74	0.73	15	0.74	0.80	0.79	15	0.37	0.42	0.42	15	0.68	0.54	0.86
14	0.78	0.78	0.75	14	0.78	0.85	0.81	14	0.52	0.53	0.53	14	0.72	0.57	0.89
13	0.80	0.82	0.80	13	0.79	0.86	0.83	13	0.61	0.61	0.62	13	0.83	0.67	0.91
12	0.81	0.84	0.83	12	0.83	0.87	0.86	12	0.66	0.70	0.72	12	0.83	0.66	0.93
11	0.83	0.87	0.88	11	0.84	0.89	0.86	11	0.67	0.71	0.77	11	0.84	0.67	0.96
10	0.82	0.87	0.89	10	0.88	0.92	0.89	10	0.84	0.81	0.81	10	0.85	0.67	0.98
9	0.88	0.95	0.94	9	0.87	0.92	0.90	9	0.91	0.89	0.87	9	0.82	0.66	0.99
8	0.92	0.95	0.95	8	0.91	0.94	0.95	8	0.92	0.90	0.89	8	0.81	0.66	0.99
7	0.92	0.95	0.97	7	0.96	0.98	0.97	7	0.96	0.96	0.94	7	0.78	0.65	0.99
6	0.91	0.96	0.97	6	0.96	0.97	0.97	6	0.96	0.97	0.96	6	0.78	0.65	1.00
5	0.91	0.97	0.97	5	0.98	0.98	0.99	5	0.95	0.95	0.94	5	0.78	0.66	1.00
									20 approximate H				20 approximate H		

Gap% vs Hardness summary

	Pearson	>0.5	>0.6	>0.7	>0.8	>0.9	Sum
Network_02	TX 500	18	16	15	12	9	70
Network_06	TX 2000	11	9	8	7	6	41
Network_13	TX 10,000	12	11	9	8	7	47
Network_30	TX 30,000	20	20	18	18	14	90

	Pearson	>0.5	>0.6	>0.7	>0.8	>0.9	Sum
Network_03	PNNL 793	20	20	20	20	20	100
Network_70	PNNL 2312	12	10	8	7	6	43
Network_08	PNNL 3022	20	20	20	19	16	95
Network_09	PNNL 4918	20	19	18	16	14	87

	Pearson	>0.5	>0.6	>0.7	>0.8	>0.9	Sum
Network_75	WI 2742	15	14	14	13	11	67
Network_82	WI 3970+	15	15	12	11	8	61
Network_83	WI 4020	20	19	16	14	10	79
Network_86	WI 4619	16	13	12	11	8	60
Network_88	WI 4837	20	20	20	18	14	92
Network_12	WI 8718	18	18	15	13	9	73
Network_14	WI 10,480	19	18	17	15	10	79
Network_20	WI 18,877+	14	13	12	10	9	58
Network_25	WI 24,464	19	18	18	17	13	85

Sum from	Sum to	Networks
80	100	6
60	79	7
40	59	4

Observations/Conclusions

- Gap% agrees reasonably well with Coffrin Hardness values.
- Approximate Hardness values correlate well when not mixed with other values
- The source of differences is difficult to ascertain.
- Another metric needed to make the determination
  - Support Vector Machine (machine learning) metric is under development
  - SVM will be an *a priori* method

- Distribution of difficulty seems reasonable.
- Failures due to other causes.

- *Why* some scenarios are harder is not currently discernable. Reasons likely complex.

Questions?

GRID OPTIMIZATION (GO) COMPETITION

Special Thanks to
- Dick O’Neill
- Tim Heidel
- Patrick McGrath
- Kory Hedman
- David Guarrera
- Ray Duthu
- Ashley Arigoni
- Joey L’etoile

@ ARPA-E

Special Thanks to
- Feng Pan
- Jesse Holzer
- Arun Veeramany
- Olga Kuchar

@PNNL

- Carleton Coffrin

@LANL