

Benchmarking Groth16 Proving System

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October 2022

This serves as a guide for navigating the excel sheets containing the benchmarks. Each **benchmark** (representing each excel sheet) has **colors** (representing the machine each workload was run on), and a **tag** on the upper right side (representing the repository benchmarked).

Benchmarks

* Parameter and Preprocessing Generation

* CPU Proof Generation

* GPU Proof Generation

Colors

* Pink = 28-core Intel(R) Xeon(R) Gold 5120 CPU @ 2.20GHz, NVIDIA P100 (Pascal Architecture) with 12 GB HBM2, 192 GB DDR4 DRAM, 128 GB SSD.

* Purple = 64-core Intel(R) Xeon(R) Platinum 8358 CPU @ 2.60GHz, NVIDIA A10 (Ampere Architecture) with 24 GB GDDR6, 1024 GB DDR4 DRAM, 2 TB SSD.

* Green = NVIDIA A40 (Ampere Architecture) with 48 GB GDDR6.

Tags

FIGURE 1 = snark-challenge-prover-reference repository:

<https://github.com/TalDerei/snark-challenge-prover-reference>

FIGURE 2 and FIGURE 3 = gpu-groth16-prover-3x:

<https://github.com/TalDerei/gpu-groth16-prover-3x>

FIGURE 4 = ZPrize (test-msm-gpu): <https://github.com/TalDerei/test-msm-gpu>

PARAMETER AND PREPROCESSING GENERATION

Parameter Generation Benchmarking					FIGURE 1
snark-challenge-prover-reference repository: https://github.com/TalDereis/snark-challenge-prover-reference					
Generating the public parameters (proving and verification keys) and inputs on CPU (there isn't a GPU option)					Execution Time = seconds
Intel(R) Xeon(R) Gold 5120 CPU @ 2.20GHz					CPU Utilization = percent
Core Count: 28	Memory (GB): 192 GB	Network bandwidth (Gbps): 50	Boot Disk: 128 GB	Year: Q3 2017	Memory Utilization = GB
	2*15	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Parameter File Size
		30.33	0		
		30.06	0		
Total:		30.195	0	13M	37M
	2*16	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Parameter File Size
		43.47	0.192		
		43.53	0.192		
Total:		43.5	0.192	25M	73M
	2*17	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Parameter File Size
		53.39	1.426944		
		53.75	1.426792		
Total:		53.57	1.426369	49M	145M
	2*18	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Parameter File Size
		98.93	2.153522765		
		98.34	2.1736512		
Total:		98.635	2.163589982	97M	289M
	2*19	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Parameter File Size
		147.74	4.6699008		
		148.33	4.7122944		
Total:		148.035	4.6910976	193M	577M
	2*20	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Parameter File Size
		270.99	9.312		
		272.45	9.039017414		
Total:		271.72	9.175508707	385M	1.2G
	2*21	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Parameter File Size
		584.49	19.0272		
		581.79	19.2		
Total:		583.14	19.1136	769M	2.3G
	2*22	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Parameter File Size
		1115.58	36.9408		
		1113.57	36.8632		
Total:		1114.575	36.912	1.6G	4.6G
	2*23	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Parameter File Size
		2016.29	62.4768		
		2014.33	61.92		
Total:		2015.31	62.1984	3.1	9.1
	2*24	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Parameter File Size
		3568.72	124.9536		
		3563.53	124.8576		
Total:		3566.125	124.9056		
	2*25	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Parameter File Size
		Process killed due to insufficient memory (192 GB)			
Total:					
Parameter Preprocessing Generation Benchmarking					FIGURE 3
snark-challenge-prover-reference repository: https://github.com/TalDereis/snark-challenge-prover-reference					
Generating the public parameters (proving and verification keys) and inputs on CPU (there isn't a GPU option)					Execution Time = seconds
Intel(R) Xeon(R) Platinum 8358 CPU @ 2.60GHz					CPU Utilization = percent
Core Count: 128	Memory (GB): 1024 GB	Network bandwidth (Gbps): 50	Boot Disk: 128 GB	Year: Q2 2021	Memory Utilization = GB
	2*15	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Preprocessing File Size
		34.11	0		
		34.12	0		
Total:		34.115	0	13M	745M
	2*16	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Preprocessing File Size
		62.28	1.02		
		62.29	1.02		
Total:		62.285	1.02	25M	1.5G
	2*17	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Preprocessing File Size
		104.38	2.46		
		104.32	2.46		
Total:		104.35	2.46	49M	3.0G
	2*18	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Preprocessing File Size
		199.55	4.92		
		199.65	4.81		
Total:		199.5	4.855	97M	5.9G
	2*19	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Preprocessing File Size
		379.64	9.83		
		378.93	9.83		
Total:		379.285	9.83	193M	12G

Parameter Generation Benchmarking					FIGURE 2
snark-challenge-prover-reference repository: https://github.com/TalDereis/snark-challenge-prover-reference					
Generating the public parameters (proving and verification keys) and inputs on CPU (there isn't a GPU option)					Execution Time = seconds
Intel(R) Xeon(R) Platinum 8358 CPU @ 2.60GHz					CPU Utilization = percent
Core Count: 128	Memory (GB): 1024 GB	Network bandwidth (Gbps): 50	Boot Disk: 128 GB	Year: Q2 2021	Memory Utilization = GB
	2*15	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Parameter File Size
		8.62	0		
		9.16	0		
Total:		8.89	0	13M	37M
	2*16	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Parameter File Size
		18.68	0.512		
		18.52	0.512		
Total:		18.6	0.512	25M	73M
	2*17	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Parameter File Size
		24.89	1.02		
		25.07	1.02		
Total:		24.96	1.02	49M	145M
	2*18	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Parameter File Size
		58.76	2.46		
		58.54	2.46		
Total:		58.65	2.46	97M	289M
	2*19	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Parameter File Size
		95.13	4.71		
		95.21	4.81		
Total:		95.17	4.76	193M	577M
	2*20	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Parameter File Size
		171.57	8.91		
		172.42	8.8		
Total:		171.995	8.855	385M	1.2G
	2*21	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Parameter File Size
		393.23	19.15		
		393.98	19.25		
Total:		393.605	19.2	769M	2.3G
	2*22	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Parameter File Size
		761.85	36.86		
		757.56	36.97		
Total:		759.705	36.915	1.6G	4.6G
	2*23	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Parameter File Size
		1358.07	61.92		
		1362.01	61.19		
Total:		1360.04	61.555	3.1G	9.1G
	2*24	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Parameter File Size
		2231.07	120.52		
		2235.06	120.55		
Total:		2233.065	120.535	6.1G	19G
	2*25	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Parameter File Size
		3907.86	240.438		
		3901.12	214.52		
Total:		3904.49	227.479	12.2G	40G
Parameter Generation Benchmarking					FIGURE 4
ZPrize (test-msm-gpu): https://github.com/TalDereis/test-msm-gpu					
Benchmarking ZPrize's MSM parameter generation on CPU (there isn't a GPU option) -- this is not comparable to running a fully complete trusted setup ceremony required by a prover					
Intel(R) Xeon(R) Platinum 8358 CPU @ 2.60GHz					
Core Count: 128	Memory (GB): 1024 GB	Network bandwidth (Gbps): 50	Boot Disk: 128 GB	Year: Q2 2021	
	2*15	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)		
		0.051	Negligible		
		0.046			
Total:		0.0485			
	2*16	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)		
		0.06	Negligible		
		0.061			
Total:		0.0605			
	2*17	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)		
		0.08	Negligible		
		0.076			
Total:		0.078			
	2*18	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)		
		0.11	Negligible		
		0.111			
Total:		0.1105			
	2*19	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)		
		0.174	Negligible		
		0.173			
Total:		0.1735			

		2*20	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Preprocessing File Size
			754.57	20.07		
			755.43	20.17		
Total:			755	20.12	385M	24G
		2*21	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Preprocessing File Size
			1499.83	38.71		
			1503.98	38.8		
Total:			1501.91	38.655	769M	47G
		2*22	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Preprocessing File Size
			3063.88	78.03		
			3065.65	77.93		
Total:			3064.765	77.98	1.6G	94G
		2*23	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Preprocessing File Size
			6142.21	156.04		
			6145.65	156.13		
Total:			6143.93	156.085	3.1G	187G
		2*24	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Preprocessing File Size
			11913.42	311.78		
			11917.11	310.26		
Total:			11915.265	311.02	6.1G	373G
		2*25	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)	Input File Size	Preprocessing File Size
			23234.77	620.24		
			23239.12	621.42		
Total:			23236.945	620.83	12.2	751G

		2*20	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)
			0.316	Negligible
			0.304	
Total:			0.31	
		2*21	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)
			0.568	Negligible
			0.563	
Total:			0.566	
		2*22	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)
			1.09	Negligible
			1.09	
Total:			1.09	
		2*23	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)
			2.02	Negligible
			2.19	
Total:			2.105	
		2*24	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)
			3.82	Negligible
			3.63	
Total:			3.725	
		2*25	Parameter Generation (Execution Time)	Parameter Generation (Memory Utilization)
			6.33	Negligible
			6.13	
Total:			6.23	

CPU PROOF GENERATION

FIGURE 1

CPU Benchmarking.				Execution Time = seconds CPU Utilization = percent Memory Utilization = GB			
snark-challenge-prover-reference repository: https://github.com/TalDerefi/snark-challenge-prover-reference							
Intel(R) Xeon(R) Gold 5120 CPU @ 2.20GHz OCPU count: 28Memory (GB): 192 GBNetwork bandwidth (Gbps): 50Boot Disk: 128 GB							
Size (2^15)							
CPU Program (Execution Time)		CPU Program (CPU Utilization)		CPU Program (Memory Utilization)			
5.36		100		0			
5.37		100		0			
5.37		100		0			
Total:	5.366666667	100		0			
CPU MSM (Execution Time)		CPU FFT (Execution Time)					
4.81		0.54					
4.77		0.58					
4.76		0.57					
Total:	4.78	0.5633333333					
Size (2^16)							
CPU Program (Execution Time)		CPU Program (CPU Utilization)		CPU Program (Memory Utilization)			
9.53		100		0			
9.67		100		0			
9.65		100		0			
Total:	9.616666667	100		0			
CPU MSM (Execution Time)		CPU FFT (Execution Time)					
8.54		0.95					
8.61		1.02					
8.6		1.02					
Total:	8.583333333	0.9966666667					
Size (2^17)							
CPU Program (Execution Time)		CPU Program (CPU Utilization)		CPU Program (Memory Utilization)			
18.3		100		0.48			
17.76		100		0.48			
17.85		100		0.48			
Total:	17.97	100		0.48			
CPU MSM (Execution Time)		CPU FFT (Execution Time)					
15.79		2.42					
15.77		1.9					
15.76		2.1					
Total:	15.77333333	2.14					
Size (2^18)							
CPU Program (Execution Time)		CPU Program (CPU Utilization)		CPU Program (Memory Utilization)			
32.43		100		1.05			
32.45		100		1.05			
32.33		100		1.07			
Total:	32.40333333	100		1.056666667			
CPU MSM (Execution Time)		CPU FFT (Execution Time)					
28.94		3.29					
28.64		3.62					
28.75		3.43					
Total:	28.77666667	3.446666667					
Size (2^19)							
CPU Program (Execution Time)		CPU Program (CPU Utilization)		CPU Program (Memory Utilization)			
60.96		100		2.13			
61.05		100		2.15			
61.03		100		2.13			
Total:	61.01333333	100		2.136666667			
CPU MSM (Execution Time)		CPU FFT (Execution Time)					
53.83		6.67					
53.74		6.85					
53.8		6.84					
Total:	53.79	6.786666667					
Size (2^20)							
CPU Program (Execution Time)		CPU Program (CPU Utilization)		CPU Program (Memory Utilization)			
113.94		100		3.93			
113.4		100		3.93			
114.06		100		3.96			
Total:	113.8	100		3.94			

CPU Benchmarking.

snark-challenge-prover-reference repository: <https://github.com/TalDerefi/snark-challenge-prover-reference>

Execution Time = seconds
CPU Utilization = percent
Memory Utilization = GB

Intel(R) Xeon(R) Platinum 8358 CPU @ 2.60GHz

Core Count: 128

Memory (GB): 1024 GB

Network bandwidth (Gbps): 50

Boot Disk: 128 GB

Year: Q2 2021

Size (2^15)

CPU Program (Execution Time)

CPU Program (CPU Utilization)

CPU Program (Memory Utilization)

4.43

100

0

4.51

100

0

4.44

100

0

Total: 4.46

100

0

CPU MSM (Execution Time)

CPU FFT (Execution Time)

3.89

0.52

3.96

0.53

3.92

0.52

Total: 3.923333333

0.5233333333

Size (2^16)

CPU Program (Execution Time)

CPU Program (CPU Utilization)

CPU Program (Memory Utilization)

6.85

100

0

6.86

100

0

6.85

100

0

Total: 6.853333333

100

0

CPU MSM (Execution Time)

CPU FFT (Execution Time)

5.83

0.99

5.78

1.05

5.77

1.04

Total: 5.793333333

1.026666667

Size (2^17)

CPU Program (Execution Time)

CPU Program (CPU Utilization)

CPU Program (Memory Utilization)

12.17

100

0.52

12.15

100

0.53

12.2

100

0.52

Total: 12.17333333

100

0.5233333333

CPU MSM (Execution Time)

CPU FFT (Execution Time)

9.94

2.16

9.94

2.14

9.96

2.17

Total: 9.946666667

2.156666667

Size (2^18)

CPU Program (Execution Time)

CPU Program (CPU Utilization)

CPU Program (Memory Utilization)

21.36

100

0.92

20.55

100

0.93

20.72

100

0.93

Total: 20.87666667

100

0.9266666667

CPU MSM (Execution Time)

CPU FFT (Execution Time)

17.36

3.86

16.67

3.72

16.93

3.75

Total: 16.98666667

3.776666667

Size (2^19)

CPU Program (Execution Time)

CPU Program (CPU Utilization)

CPU Program (Memory Utilization)

34.62

100

1.74

34.73

100

1.74

34.53

100

1.74

Total: 34.62666667

100

1.74

CPU MSM (Execution Time)

CPU FFT (Execution Time)

27.01

7.38

26.96

7.53

26.99

7.45

Total: 26.98666667

7.453333333

Size (2^20)

CPU Program (Execution Time)

CPU Program (CPU Utilization)

CPU Program (Memory Utilization)

63.12

100

3.48

63.72

100

3.38

63.43

100

3.48

Total: 63.42333333

100

3.446666667

FIGURE 2

	CPU MSM (Execution Time)	CPU FFT (Execution Time)							
	100.09	12.94							
	98.97	13.5							
	100.19	12.97							
Total:	99.75	13.13666667							
Size (2*21)									
	CPU Program (Execution Time)	CPU Program (CPU Utilization)	CPU Program (Memory Utilization)						
	211.62	100	7.85						
	213.86	100	7.83						
	212.34	100	7.87						
Total:	212.606667	100	7.85						
	CPU MSM (Execution Time)	CPU FFT (Execution Time)							
	185.84	23.94							
	188.23	23.77							
	186.3	24.17							
Total:	186.79	23.96							
Size (2*22)									
	CPU Program (Execution Time)	CPU Program (CPU Utilization)	CPU Program (Memory Utilization)						
	401.05	100	16.9						
	401.58	100	16.86						
	402.34	100	16.88						
Total:	401.656667	100	16.88						
	CPU MSM (Execution Time)	CPU FFT (Execution Time)							
	350.43	46.87							
	349.68	48.13							
	350.17	48.44							
Total:	350.093333	47.8133333							
Size (2*23)									
	CPU Program (Execution Time)	CPU Program (CPU Utilization)	CPU Program (Memory Utilization)						
	773.43	100	30.85						
	777.78	100	30.8						
	774.68	100	30.82						
Total:	775.296667	100	30.8233333						
	CPU MSM (Execution Time)	CPU FFT (Execution Time)							
	667.2	98.66							
	670.35	99.87							
	672.33	98.5							
Total:	669.96	99.01							
Size (2*24)									
	CPU Program (Execution Time)	CPU Program (CPU Utilization)	CPU Program (Memory Utilization)						
	1490.77	100	61.54						
	1492.15	100	61.67						
	1493.25	100	61.86						
Total:	1492.056667	100	61.69						
	CPU MSM (Execution Time)	CPU FFT (Execution Time)							
	1275.43	200.85							
	1270.87	206.05							
	1250.37	205.75							
Total:	1265.556667	204.216667							
Size (2*25)									
	CPU Program (Execution Time)	CPU Program (CPU Utilization)	CPU Program (Memory Utilization)						
		Process killed due to insufficient memory (192 GB)							
Total:									
	CPU MSM (Execution Time)	CPU FFT (Execution Time)							
Total:									

	CPU MSM (Execution Time)	CPU FFT (Execution Time)							
	48.38	14.29							
	49.3	13.96							
	48.67	14.14							
Total:	48.78333333	14.13							
Size (2*21)									
	CPU Program (Execution Time)	CPU Program (CPU Utilization)			CPU Program (Memory Utilization)				
	113.34	100			6.94				
	115.41	100			6.96				
	112.93	100			7.07				
Total:	113.8933333	100			6.99				
	CPU MSM (Execution Time)	CPU FFT (Execution Time)							
	88.25	24.2							
	88.14	24.31							
	89.74	24.74							
Total:	88.71	24.41666667							
Size (2*22)									
	CPU Program (Execution Time)	CPU Program (CPU Utilization)			CPU Program (Memory Utilization)				
	211.37	100			13.4				
	211.42	100			13.31				
	211.34	100			13.31				
Total:	211.3766667	100			13.34				
	CPU MSM (Execution Time)	CPU FFT (Execution Time)							
	160.21	49.4							
	158.76	50.84							
	159.86	50.32							
Total:	159.61	50.18666667							
Size (2*23)									
	CPU Program (Execution Time)	CPU Program (CPU Utilization)			CPU Program (Memory Utilization)				
	361.82	100			26.73				
	361.16	100			26.93				
	361.73	100			26.73				
Total:	361.57	100			26.79666667				
	CPU MSM (Execution Time)	CPU FFT (Execution Time)							
	258.73	99.61							
	258.78	98.81							
	258.75	99.52							
Total:	258.7533333	99.31333333							
Size (2*24)									
	CPU Program (Execution Time)	CPU Program (CPU Utilization)			CPU Program (Memory Utilization)				
	770.81	100			53.84				
	771.35	100			53.81				
	773.21	100			53.71				
Total:	771.79	100			53.78666667				
	CPU MSM (Execution Time)	CPU FFT (Execution Time)							
	552.75	210.78							
	553.21	211.72							
	554.32	209.34							
Total:	553.4266667	210.6133333							
Size (2*25)									
	CPU Program (Execution Time)	CPU Program (CPU Utilization)			CPU Program (Memory Utilization)				
	1542.21	100			110.32				
	1539.59	100			110.92				
	1541.24	100			109.34				
Total:	1541.013333	100			110.1933333				
	CPU MSM (Execution Time)	CPU FFT (Execution Time)							
	1110.12	425.32							
	1113.43	425.42							
	1114.24	422.35							
Total:	1112.596667	424.3633333							

GPU PROOF GENERATION

GPU Benchmarking - gpusmith6-prover-3s https://github.com/Develogun/gpusmith6-prover-3s						Execution Time + seconds GPU Utilization + percent Memory Utilization + GB		Note: MSM and FFTs run in parallel		FIGURE 1
Shape: BM GPU D2	GPUs	Architecture	CPU Interconnect	CPU Memory	CPU Cores	System Memory	Network			
NVIDIA P100	Pascal	N/A	16 GB HBM2	3554	192 GB	2x 25 Gbps				
Size (2*16)										
GPU Program (Execution Time)		GPU Program (GPU Utilization)		GPU Program (VRAM Memory Utilization)		GPU Program (System Memory Utilization)				
3.46		100		1.00		1.00				
3.47		100		1.00		1.00				
3.46		100		1.00		1.00				
Total: 3.46333333		100		1.00		1.00				
GPU MSM (Execution Time)		GPU FFT (Execution Time)								
3.44		0.86								
3.42		0.87								
3.43		0.87								
Total: 3.43		0.86								
Size (2*16)										
GPU Program (Execution Time)		GPU Program (GPU Utilization)		GPU Program (VRAM Memory Utilization)		GPU Program (System Memory Utilization)				
6.82		100		1.9		1.9				
6.85		100		1.9		1.42				
6.82		100		1.9		1.44				
Total: 6.83333333		100		1.9		1.57333333				
GPU MSM (Execution Time)		GPU FFT (Execution Time)								
6.79		1.31								
6.79		1.3								
6.73		1.31								
Total: 6.76888887		1.30888887								
Size (2*17)										
GPU Program (Execution Time)		GPU Program (GPU Utilization)		GPU Program (VRAM Memory Utilization)		GPU Program (System Memory Utilization)				
13.84		100		3.91		3.97				
14.31		100		3.91		3.95				
14.22		100		3.91		3.95				
Total: 14.16666667		100		3.91		3.95888887				
GPU MSM (Execution Time)		GPU FFT (Execution Time)								
13.88		1.97								
14.26		1.95								
13.82		1.92								
Total: 14.01666667		1.95								
Size (2*18)										
GPU Program (Execution Time)		GPU Program (GPU Utilization)		GPU Program (VRAM Memory Utilization)		GPU Program (System Memory Utilization)				
24.27		100		6.6		6.69				
24.21		100		6.6		6.67				
24.12		100		6.6		6.67				
Total: 24.23333333		100		6.6		6.67888887				
GPU MSM (Execution Time)		GPU FFT (Execution Time)								
24.2		3.91								
24.04		3.45								
24.01		3.48								
Total: 24.03333333		3.69888887								
Size (2*19)										
GPU Program (Execution Time)		GPU Program (GPU Utilization)		GPU Program (VRAM Memory Utilization)		GPU Program (System Memory Utilization)				
46.7		100		12.9		12.91				
47		100		12.9		13.77				
46.85		100		12.9		13.76				
Total: 46.85		100		12.9		13.77888887				
GPU MSM (Execution Time)		GPU FFT (Execution Time)								
46.33		6.94								
46.83		7.14								
46.44		7.05								
Total: 46.46888887		7.04333333								
Size (2*20)										
GPU Program (Execution Time)		GPU Program (GPU Utilization)		GPU Program (VRAM Memory Utilization)		GPU Program (System Memory Utilization)				
76.25		100		16		16.84				
76.71		100		16		16.82				
76.65		100		16		16.67				
Total: 76.53888887		100		16		16.77888887				
GPU MSM (Execution Time)		GPU FFT (Execution Time)								
76.45		13.13								
75.01		13.11								
75.43		13.12								
Total: 74.99888887		13.12								
Size (2*21)										
GPU Program (Execution Time)		GPU Program (GPU Utilization)		GPU Program (VRAM Memory Utilization)		GPU Program (System Memory Utilization)				
176.26		100		16		16.86				
176.69		100		16		15.47				
176.79		100		16		15.79				
Total: 176.68888887		100		16		16.07				
GPU MSM (Execution Time)		GPU FFT (Execution Time)								
174.71		26.2								
175.16		26.94								
175.32		25.73								
Total: 175.66333333		26.62333333								
Size (2*22)										
GPU Program (Execution Time)		GPU Program (GPU Utilization)		GPU Program (VRAM Memory Utilization)		GPU Program (System Memory Utilization)				
367.88		100		16		167.26				
367.55		100		16		156.87				
367.79		100		16		157.16				
Total: 367.77333333		100		16		160.57888887				
GPU MSM (Execution Time)		GPU FFT (Execution Time)								
337.35		69.85								
338.29		51.23								
338.53		50.45								
Total: 338.05888887		50.51								
Size (2*23)										
GPU Program (Execution Time)		GPU Program (GPU Utilization)		GPU Program (VRAM Memory Utilization)		GPU Program (System Memory Utilization)				
Total:										
GPU MSM (Execution Time)		GPU FFT (Execution Time)								
Total:										
Size (2*24)										
GPU Program (Execution Time)		GPU Program (GPU Utilization)		GPU Program (VRAM Memory Utilization)		GPU Program (System Memory Utilization)				
Total:										
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FIGURE 4FIGURE 4

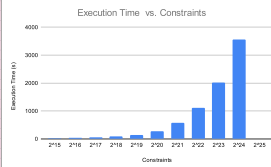
CHARTS

PARAMETER BENCHMARKING

FIGURE 1

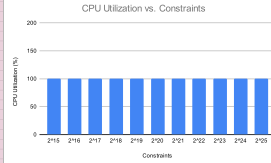
Parameter Generation (Execution Time)

Constraints	Execution Time
2'15	38.21
2'16	43.5
2'17	53.57
2'18	58.54
2'19	148.03
2'20	271.72
2'21	583.14
2'22	1114.58
2'23	2015.31
2'24	3566.13
2'25	N/A



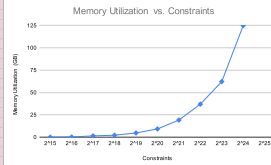
Parameter Generation (CPU Utilization)

Constraints	CPU Utilization
2'15	100
2'16	100
2'17	100
2'18	100
2'19	100
2'20	100
2'21	100
2'22	100
2'23	100
2'24	100
2'25	100



Parameter Generation (Memory Utilization)

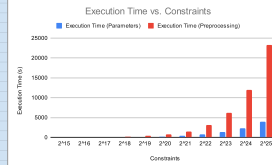
Constraints	Memory Utilization
2'15	0
2'16	0.19
2'17	1.43
2'18	2.18
2'19	4.69
2'20	9.18
2'21	19.31
2'22	36.91
2'23	62.21
2'24	124.91
2'25	N/A



FIGURES 2 + 3

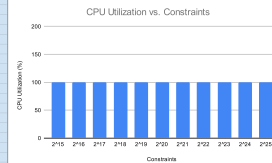
Parameter Generation (Execution Time)

Constraints	Execution Time (Parameters)	Execution Time (Preprocessing)
2'15	8.89	34.12
2'16	19.8	62.29
2'17	24.88	104.36
2'18	58.05	198.6
2'19	95.17	379.29
2'20	172	705
2'21	393.81	1501.91
2'22	788.71	3064.77
2'23	1580.84	6163.53
2'24	2233.07	11915.27
2'25	3504.48	23237.61



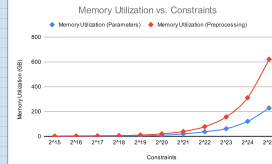
Parameter Generation (CPU Utilization)

Constraints	CPU Utilization
2'15	100
2'16	100
2'17	100
2'18	100
2'19	100
2'20	100
2'21	100
2'22	100
2'23	100
2'24	100
2'25	100



Parameter Generation (Memory Utilization)

Constraints	Memory Utilization (Parameters)	Memory Utilization (Preprocessing)
2'15	0	0
2'16	0.512	1.02
2'17	1.02	2.48
2'18	2.48	4.87
2'19	4.76	9.83
2'20	8.89	20.12
2'21	19.2	38.86
2'22	36.91	77.58
2'23	61.55	156.09
2'24	120.53	311.02
2'25	227.47	620.81



Parameter Generation (File Constraints)

Constraints	Input File	Parameter File	Preprocessing File
2'15	0.13	0.37	0.745
2'16	0.25	0.73	1.5
2'17	0.49	0.15	3
2'18	0.97	0.31	5.9
2'19	0.193	0.58	12
2'20	0.39	1.2	24
2'21	0.77	2.3	47
2'22	1.6	4.6	94
2'23	3.1	9.1	187
2'24	6.1	18	373
2'25	12.2	40	751

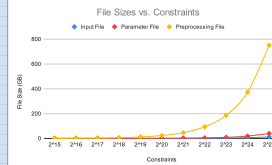
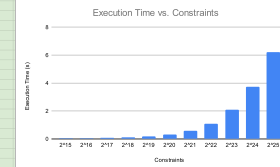


FIGURE 4

Parameter Generation (Execution Time)

Constraints	Execution Time
2'15	0.05
2'16	0.08
2'17	0.08
2'18	0.11
2'19	0.17
2'20	0.31
2'21	0.97
2'22	1.68
2'23	2.105
2'24	3.73
2'25	6.33

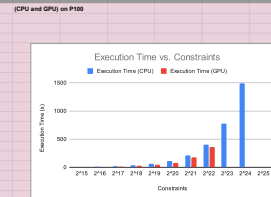


CPU / GPU BENCHMARKING

FIGURE 1

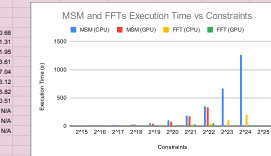
CPU and GPU Program (Execution Time)

Constraints	Execution Time (CPU)	Execution Time (GPU)
2'15	5.37	3.46
2'16	9.52	6.85
2'17	17.97	14.56
2'18	32.4	29.23
2'19	61.01	48.85
2'20	113.5	75.54
2'21	212.81	176.86
2'22	401.88	359.87
2'23	776.31	N/A
2'24	1402.08	N/A
2'25	N/A	N/A



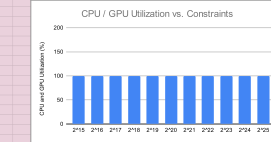
CPU and GPU Program (MSM and FFT)

Constraints	MSM (CPU)	MSM (GPU)	FFT (CPU)	FFT (GPU)
2'15	4.76	5.43	0.56	0.86
2'16	8.58	8.79	1.01	1.31
2'17	15.71	14.02	2.44	1.56
2'18	28.78	24.08	3.45	3.81
2'19	53.79	46.47	6.79	7.56
2'20	89.75	79	13.44	13.32
2'21	188.79	175.09	23.99	25.52
2'22	350.39	338.08	47.81	50.57
2'23	689.56	N/A	95.61	N/A
2'24	1285.58	N/A	210.22	N/A
2'25	N/A	N/A	N/A	N/A



CPU and GPU Program (CPU / GPU Utilization)

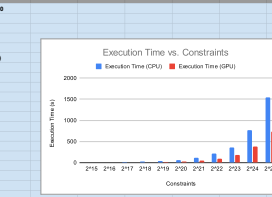
Constraints	CPU and GPU Utilization
2'15	100
2'16	100
2'17	100
2'18	100
2'19	100
2'20	100
2'21	100
2'22	100
2'23	100
2'24	100
2'25	100



FIGURES 2

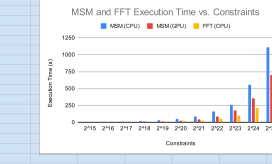
CPU and GPU Program (Execution Time)

Constraints	Execution Time (CPU)	Execution Time (GPU)
2'15	4.46	1.45
2'16	6.85	2.12
2'17	12.17	3.6
2'18	20.68	6.51
2'19	34.83	12.19
2'20	63.42	23.29
2'21	113.89	43.46
2'22	211.38	87.08
2'23	381.97	188.39
2'24	771.79	377.96
2'25	1541.01	732.32



CPU and GPU Program (MSM and FFT)

Constraints	MSM (CPU)	MSM (GPU)	FFT (CPU)
2'15	32	46	0.32
2'16	5.79	2.11	1.03
2'17	9.56	3.57	2.16
2'18	16.99	6.43	3.79
2'19	28.99	11.96	7.45
2'20	48.78	22.85	14.13
2'21	88.71	42.52	24.42
2'22	159.61	85.26	38.19
2'23	285.75	176.45	66.31
2'24	553.43	358.31	270.81
2'25	1112.61	709.52	424.36



CPU and GPU Program (CPU / GPU Utilization)

Constraints	CPU and GPU Utilization
2'15	100
2'16	100
2'17	100
2'18	100
2'19	100
2'20	100
2'21	100
2'22	100
2'23	100
2'24	100
2'25	100

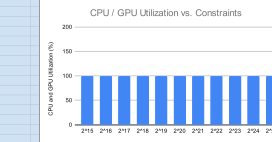
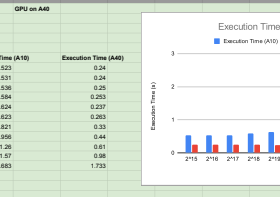


FIGURE 4

GPU Program (Execution Time)

Constraints	Execution Time (A10)	Execution Time (A40)
2'15	0.521	0.24
2'16	0.531	0.24
2'17	0.538	0.25
2'18	0.546	0.253
2'19	0.624	0.227
2'20	0.823	0.283
2'21	0.921	0.33
2'22	0.958	0.44
2'23	1.36	0.61
2'24	1.57	0.98
2'25	2.683	1.733



GPU Program (GPU Memory Utilization)

Constraints	Memory Utilization (A10)	Memory Utilization (A40)
2'15	1.87	2
2'16	1.678	2.05
2'17	1.688	2.08
2'18	1.707	2.1
2'19	1.75	2.14
2'20	1.84	2.23
2'21	2.01	2.4
2'22	2.35	2.75
2'23	3.04	3.43
2'24	4.42	4.81
2'25	7.17	7.88

