A Memo on Exploration of SPLASH-2 Input Sets

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Abstract

This memo presents the study of the exploration of input sets for SPLASH-2. Based on experimental data, we generate a modernized SPLASH-2, a.k.a., SPLASH-2x, by selecting multiple scales of input sets. SPLASH-2x will be integrated into PARSEC framework.

1. Introduction

SPLASH-2 benchmark suite [4] includes applications and kernels mostly in the area of high performance computing (HPC). It has been widely used to evaluate multiprocessors and their designs for the past 15 years. During the past few years, we have collaborated with several institutions to develop PARSEC benchmark suite [1] which include 13 applications and kernels in emerging areas such as data mining, finance, physical modeling. data clustering and data deduplication. Recent studies [2] show that SPLASH-2 and PARSEC benchmark suites complement each other well in term of diversity of architectural characteristics such as instruction distribution, cache miss rate and working set size. In order to provide computer architects with the convenient use of both benchmarks, we have integrated SPLASH-2 into the PARSEC environment in this release. Users can now build, run and manage both workloads under the same environment framework.

The new release of SPLASH-2 is called SPLASH-2x because it also has several input datasets at different scale. Since SPLASH-2 was designed many years ago, their standard input datasets are relatively small for contemporary shared memory multiprocessors. To scale up the input sets for SPLASH-2, we have explored the input space of the SPLASH2 workloads. Our method is to analyze the impact of various inputs and to select multiple scales reasonable input sets. We have extracted input parameters from source codes and designed a framework to automatically generate about 1,600 refined combinations of input parameters, execute workloads with the input combinations and collect measurement data. To investigate the impact of different input sets on program behavior, we mainly use two metrics, i.e., execution time and memory footprint size. Experimental results show that most programs' behavior is influenced by less than three input parameters. We picked those parameters and selected values for them to generate multiple scales of input sets, i.e., Native (< 15 minutes), Simlarge (<16 seconds), Simmedium (<4 seconds) and Simsmall (<1 second), similar to PARSEC's criterion [3]. SPLASH-2x will be released with these input sets.

This document describes the major input parameters of the SPLASH2 workloads, presents experimental data and shows the selected input sets for SPLASH-2x.

2. Input Parameters

We extracted all input parameters from SPLASH-2 source codes. There are 81 parameters in total and we assigned a value range for each parameter. A typical value range is designated by *MIN*, *MAX* and *DELTA*. It should be noted that *DELTA* already includes arithmetic operation. For example, a parameter assigned with the value range of "[16K, 16M], Δ=*2" will explore the following values {16K, 32K, 64K, … 4M, 8M, 16M}. We explored the whole input space and found that in fact there are only a few parameters which affect program behavior. Then we select those parameters as the principle parameters for later analysis. Table 1 illustrates those principle parameters.

In order to explore as large space as possible, we modified some original input files and slightly changed some source files. For example, we appended more random numbers into the "random.in" input file for the *water_nsuqared* and *water_spatial* workloads. We also tried to generate symmetric positive-definite matrices for the *cholesky* workload, but those matrices failed to let the program complete execution. So we have to use the original small matrices for *cholesky*.

Table 1. Exploration of Input Sets Space for principle parameters

Workload	Input Param	Range & Delta	Description
Barnes	nbody	[16K, 16M], Δ=*2	The number of particles to generate under a plummer.
	dtime	[0.010, 0.025], Δ=+0.005	The integration time-step.
	tol	[0.5, 1.0], Δ=+0.5	The cell subdivision tolerance.
Fmm	NP	[1K, 4M], Δ=*2	Number of Particles.
	TS	[5, 15], Δ=+5	Number of Time Steps.
Ocean	N	[256+2, 4096+2], Δ=*2	Simulate NxN ocean. N must be (power of 2)+2.
	R	[10^4, $5*10^4$], Δ=+10^4	Distance between grid points in meters.
	T	[14400, 28800], Δ=*2	Timestep in seconds.
Radiosity	AE	[2000, 3000], Δ=+500	Area epsilon
	BF	[$1.5*10^{-4}$, $1.5*10^{-2}$],Δ=10	BFepsilon (BF refinement)
	Model	{"room", "large room"}	Use room/large room model
Raytrace	A	{64, 128}	Enable antialiasing with n subpixels
	File	{"teapot.env","balls4.env", "car.env"}	Inpu image file
Volrend	Step	{4,10,20,50,100,500,1000}	Rotate steps
	File	{"head","head-scaleddown2", "head-scaleddown4"}	Input image file
Water	M	M=n^3, n∈[8,32], Δn=+1	The number of molecules to be simulated
	NSTEP	[3,9], Δ=+2	The number of timesteps to be simulated
Choleksy	Matrix	{tk14,..tk29}U{lshp,wr10,d750}	Sparse Symmetric Positive-Definite Matrix
Fft	M	[18, 28], Δ=+2	2^M total complex data points to be transformed.
Lu	N	[512, 16K], Δ=*2	Decompose NxN matrix.
radix	N	[64K, 512M], Δ=*2	Number of keys to sort

3. Experimental Results

We conducted experiments on a server machine. The machine is with two Intel Xeon E5430 quad-core processor, 32 GB memory and Linux 2.6.18. All SPLASH-2 workloads are compiled by GCC-4.2.1 with flag "-O3". Since our objective is to investigate input sets other than scalability, we assigned one process for each workload. We use two metrics (execution time and memory footprint size) to measure the impact on program behavior. It should be noted that we use physical resident memory size rather than virtual memory size because physical resident memory is the actual amount one program consumes.

Experimental results show that the execution time and memory size have strong correlation to input parameters. The figures in Appendix A illustrate the correlations between the two metrics and the input sets for each workload. Take BARNES as an example, there are three input parameters influencing the two metrics: 1) nbody (the number of particles to generate under a plummer) significantly changes both time and memory; 2) dtime (the integration timestep) slightly changes both time and memory; 3) tol (the cell subdivision tolerance) changes only execution time.

For more details of each workload, please refer to Appendix A.

4. Input Set Selection

We selected multiple input sets for SPLASH-2x, the modernized SPLASH-2. We adopted the criterion for PARSEC input set selection (Table 2). PARSEC criterion has six input sets, among which four are experiments of either simulations or native executions while the other two are for test and development. In this work, we focus on only the four criterions, i.e., *Simsmall*, *Simmedium*, *Simlarge* and *Native*.

Table 2. The six standardized input sets offered by PARSEC. [3]

Input Set	Description	Time	Purpose
Test	Minimal execution time	N/A	Test & Development
Simdev	Best-effort code coverage of real inputs	N/A	
Simsmall	Small-scale experiments	≤ 1s	Simulations
Simmedium	Medium-scale experiments	≤ 4s	
Simlarge	Large-scale experiments	≤ 15s	
Native	Real-world behavior	≤ 15min	Native execution

We employed the same scaling model in previous studies [3]. The simple model divides the impact of input set into two categories: **the linear part** and **the complex part**. The linear part has linear effect on the execution time and memory size while the complex part includes any other effect on the program. For example, a linear part might be simple incrementing iteration step from S to 2S and a complex part might be increasing input matrix size from N to 2N. The former increment probably only increase execution time by twice but the latter change would require 4 times of memory size and execution time.

Table 3 illustrates the overview of the input set selection of SPLASH-2x. The input set for most workloads cover both the linear impact and the complex impact. Different from most of the PARSEC workloads that have identical input sets for the complex part, the input sets of SPLASH-2x workloads exhibit more complex impacts. This difference results from the different design goals of the two benchmark suites. PARSEC is targeted to emerging applications such as video, data mining and finance which usually have fixed input size, e.g., a video frame. However, SPLASH-2 focuses on HPC applications which include a large number of matrix manipulations whose overheads are usually exponential to matrix size.

Table 3. Input Set Selection for SPLASH-2x

Workload	Input Set	Size		Reference	
		Complex	Linear	Mem	Time
Barnes	Simsmall	16K Particles, Timestep = 0.25	Tolerance = 1.0	7M	0.8s
	Simmedium	32K Particles, Timestep = 0.25	Tolerance = 1.0	26M	3.7s
	Simlarge	256K Particles,Timestep= 0.25	Tolerance = 1.0	98M	16.3s
	Native	2M Particles, Timestep = 0.15	Tolerance = 0.5	1017M	1160.0s
Fmm	Simsmall	16K Particles	Timestep = 5	10M	0.6s
	Simmedium	64K Particles	Timestep = 5	36M	2.5s
	Simlarge	256K Particles	Timestep = 5	140M	10.5s
	Native	4M Particles	Timestep = 5	2217M	176.0s
Ocean Contiguous Partition (Ocean_cp)	Simsmall	514x514 Grid	Distance=20000,Timestep = 28800	57M	0.9s
	Simmedium	1026x1026 Grid	Distance= 20000,Timestep = 28800	223M	3.6s
	Simlarge	2050x2050 Grid	Distance= 20000,Timestep = 28800	887M	14.0s
	Native	4098X4098 Grid	Distance= 10000,Timestep = 14400	3546M	254.3s
Ocean Non-Contiguous Partition (Ocean_ncp)	Simsmall	514x514 Grid	Distance= 20000,Timestep = 28800	114M	1.2s
	Simmedium	1026x1026 Grid	Distance= 20000,Timestep = 28800	337M	4.8s
	Simlarge	2050x2050 Grid	Distance= 20000,Timestep = 28800	1114M	19.0s
	Native	4098X4098 Grid	Distance= 10000,Timestep = 14400	4003M	277.0s
Radiosity	Simsmall	BF refinement =1.5e-1	Room	64M	0.4s
	Simmedium	BF refinement =1.5e-2	Room	64M	2.3s
	Simlarge	BF refinement =1.5e-3	Room	877M	16.8s
	Native	BF refinement =1.5e-4	Largeroom	1442M	241.9s
Raytrace	Simsmall	Teapot	Antialiasing w/ 8 subpixels	6M	0.6s
	Simmedium	Balls4	Antialiasing w/ 2 subpixels	6M	3.1s
	Simlarge	Balls4	Antialiasing w/ 8 subpixels	6M	12.4s
	Native	Car	Antialiasing w/ 128 subpixels	22M	225.4s
Volrend	Simsmall	Head-Scaledown4	Rotate Step = 20	1.7M	0.6s
	Simmedium	Head-Scaledown2	Rotate Step = 50	5M	4.0s
	Simlarge	Head-Scaledown2	Rotate Step = 100	5M	7.5s
	Native	Head	Rotate Step = 1000	30M	246.2s
Water Nsquared	Simsmall	8^3 Molecules	Timestep = 3	2M	1.0s
	Simmedium	15^3 Molecules	Timestep = 3	4M	3.5s
	Simlarge	20^3 Molecules	Timestep = 3	7M	19.3s
	Native	32^3 Molecules	Timestep = 7	26M	839.3s
Water Spatial	Simsmall	15^3 Molecules	Timestep = 3	3M	0.9s
	Simmedium	20^3 Molecules	Timestep = 3	6M	2.1s
	Simlarge	32^3 Molecules	Timestep = 3	23M	7.7s
	Native	100^3 Molecules	Timestep = 3	668M	233.7s
Choleksy	Simsmall	13992x13992, NZ=316740		37M	0.3s
	Simmedium	13992x13992, NZ=316740		37M	0.3s
	Simlarge	13992x13992, NZ=316740		37M	0.3s
	Native	13992x13992, NZ=316740		37M	0.3s

Table 3. Input Set Selection for SPLASH-2x (cont.)

Workload	Input Set	Size		Reference	
		Complex	Linear	Mem	Time
Fft	Simsmall	2^{20} total complex data points		49M	0.4s
	Simmedium	2^{22} total complex data points		193M	1.5s
	Simlarge	2^{24} total complex data points		769M	6.0s
	Native	2^{28} total complex data points		12G	128.5s
LU Contiguous Block (Lu_cb)	Simsmall	512x512 Matrix, Block = 16		3M	0.1s
	Simmedium	1Kx1K Matrix, Block = 16		9M	0.7s
	Simlarge	2Kx2K Matrix, Block = 16		33M	5.1s
	Native	8Kx8K Matrix, Block = 32		513M	320.7s
LU Non-Contiguous Block (Lu_cb)	Simsmall	512x512 Matrix, Block = 16		3M	0.1
	Simmedium	1Kx1K Matrix, Block = 16		9M	0.9s
	Simlarge	2Kx2K Matrix, Block = 16		33M	8.7s
	Native	8Kx8K Matrix, Block = 32		513M	509.2s
radix	Simsmall	4M Keys, Radix = 4K		65M	0.9s
	Simmedium	16M Keys, Radix = 4K		257M	3.6s
	Simlarge	64M Keys, Radix = 4K		1G	14.6s
	Native	256M Keys, Radix = 4K		4G	59.3s

5. Conclusion

SPLASH-2 is a widely used benchmark suite for shared memory machines. However, its original input sets are already obsolete. We have explored the input spaces for all of the SPLASH-2 workloads and analyzed their impact on program behavior in term of execution time and memory footprint size. We have conducted about 1600 experiments and collect a large number of data. Based on the experimental results, we have selected multiple scales of input sets to generate SPLASH-2x, a modernized SPLASH-2, which has been integrated into the PARSEC framework.

Reference

[1] Christian Bienia, Sanjeev Kumar, Jaswinder Pal Singh and Kai Li, The PARSEC Benchmark Suite: Characterization and Architectural Implications. In *Proceedings of the 17th International Conference on Parallel Architectures and Compilation Techniques*, October 2008.

[2] Christian Bienia, Sanjeev Kumar and Kai Li, PARSEC vs. SPLASH-2: A Quantitative Comparison of Two Multithreaded Benchmark Suites on Chip-Multiprocessors. In *Proceedings of the IEEE International Symposium on Workload Characterization*, September 2008

[3] Christian Bienia and Kai Li, Fidelity and Scaling of the PARSEC Benchmark Inputs. In *Proceedings of the IEEE International Symposium on Workload Characterization*, December 2010.

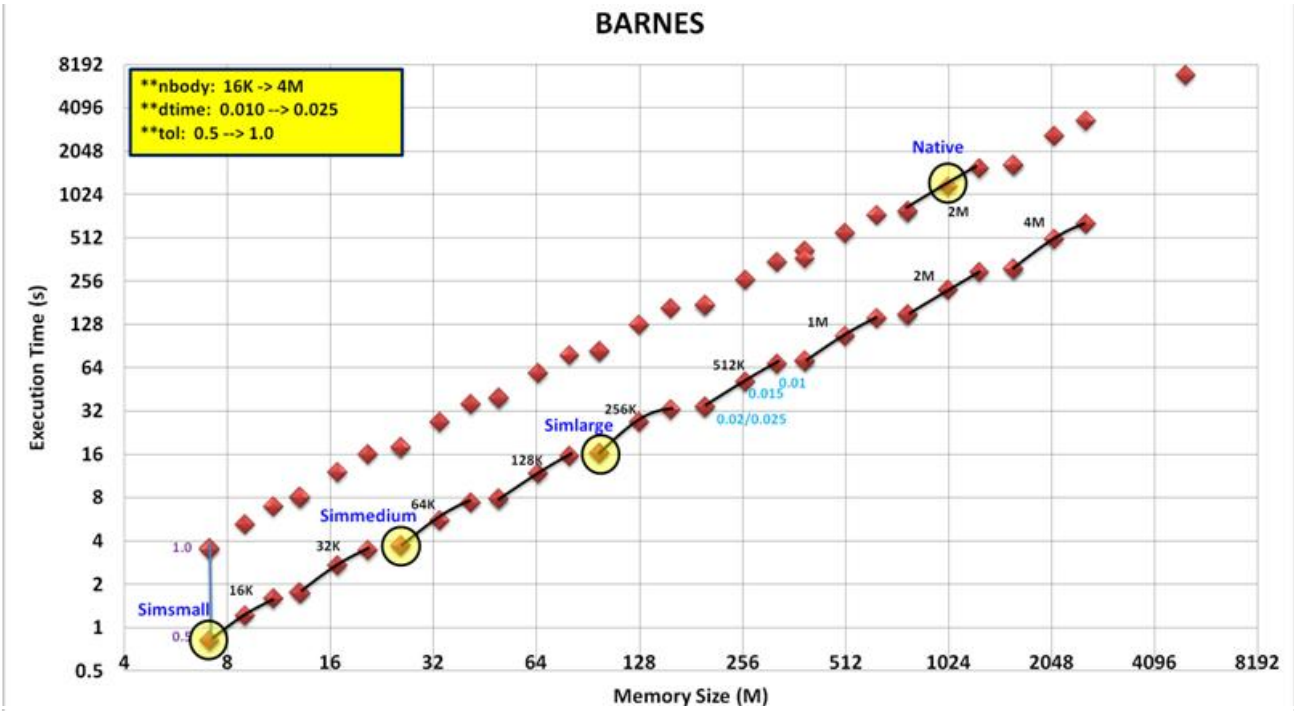
[4] Steven Cameron Woo, Moriyoshi Ohara, Evan Torrie, Jaswinder Pal Singh, and Anoop Gupta. 1995. The SPLASH-2 programs: characterization and methodological considerations. In *Proceedings of the 22nd annual international symposium on Computer Architecture*, June 1995.

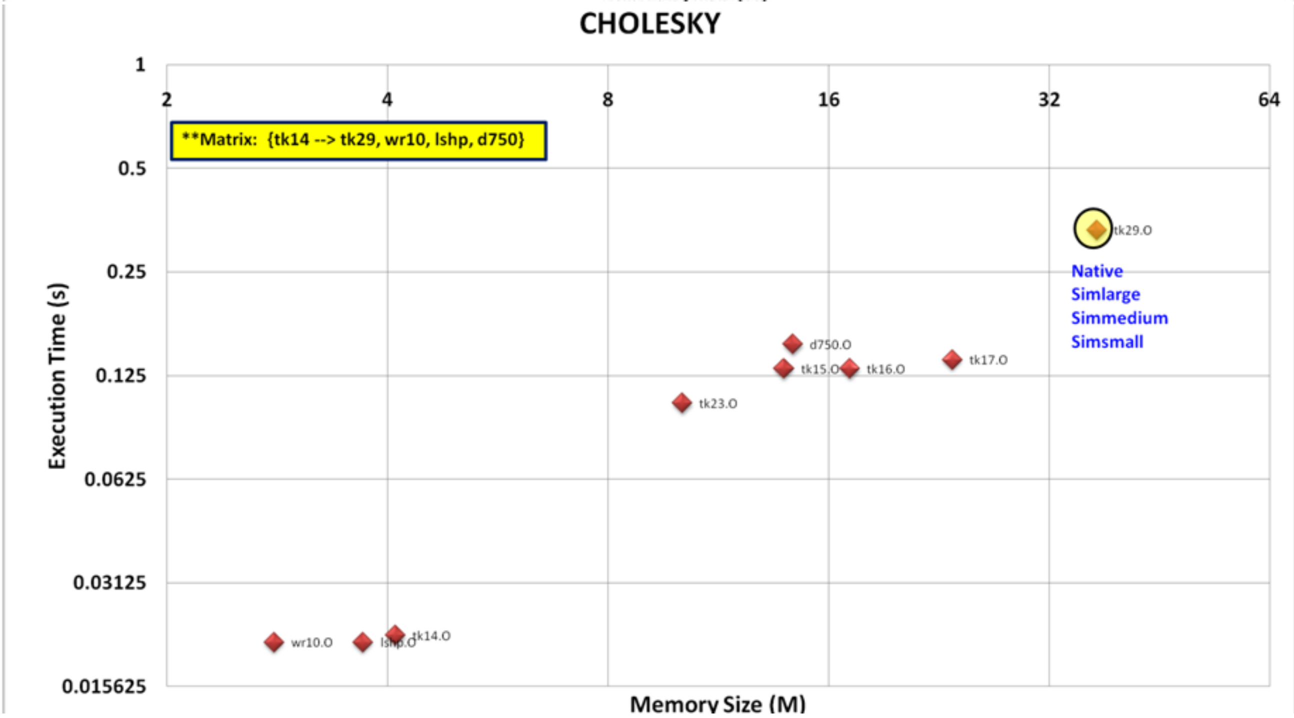
Appendix A

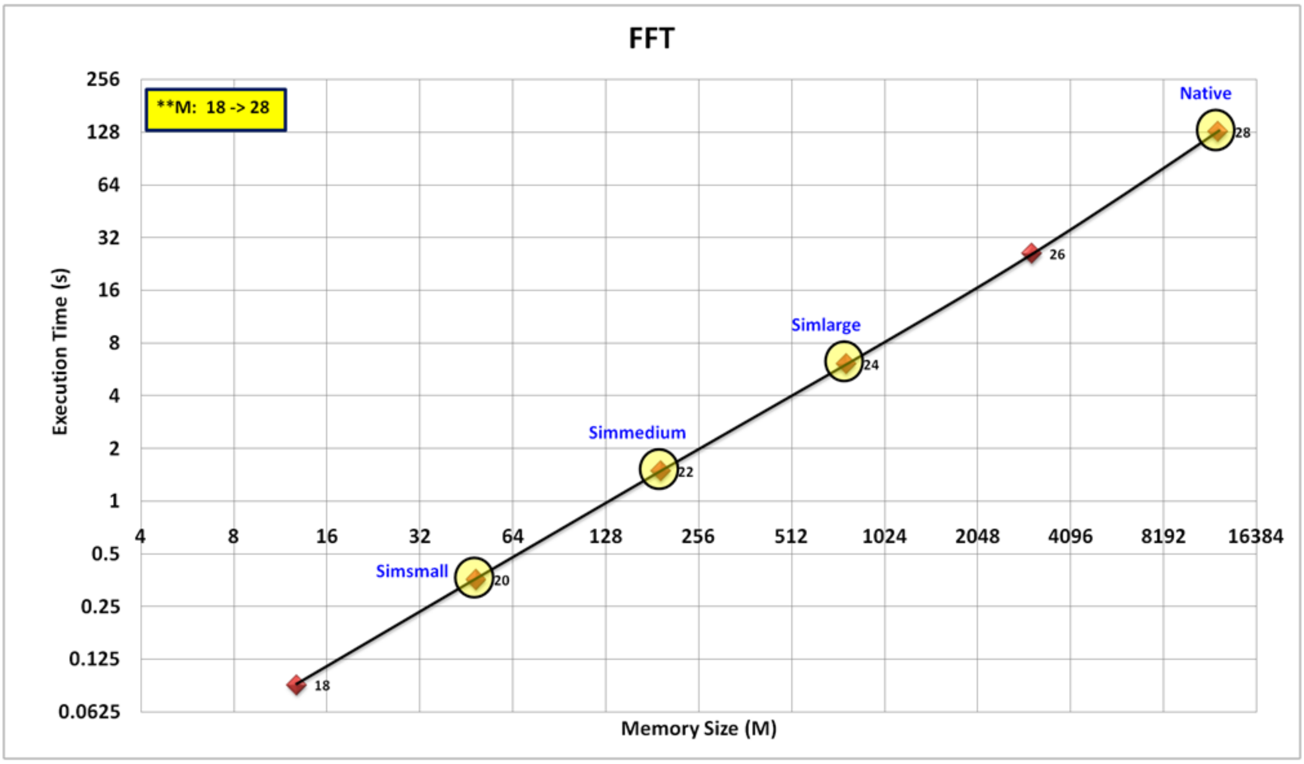
We use two metrics to measure program behavior, i.e., execution time (T) and memory footprint size (M). For the data collection phase, we use Equation (1) to collect the T and M metrics by changing input parameters. The following charts are drawn based on Equation (2). The label associated with each dot in the charts represents one combination of input parameters ***(p_1, p_2, ..., p_n)***. (NOTE: the input parameters in legend with "**" is principle parameters.)

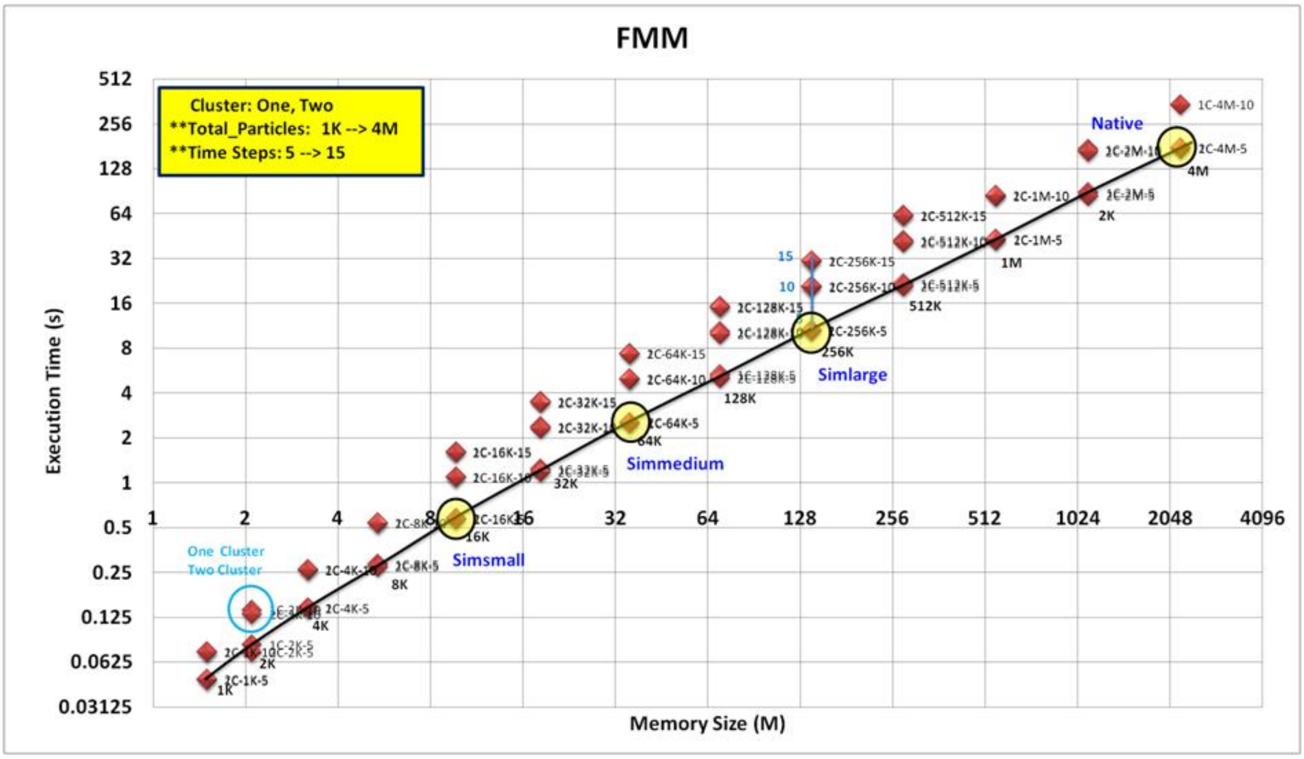
$$(T, M)=F(p_1, p_2, \ldots , p_n) \quad (1),$$

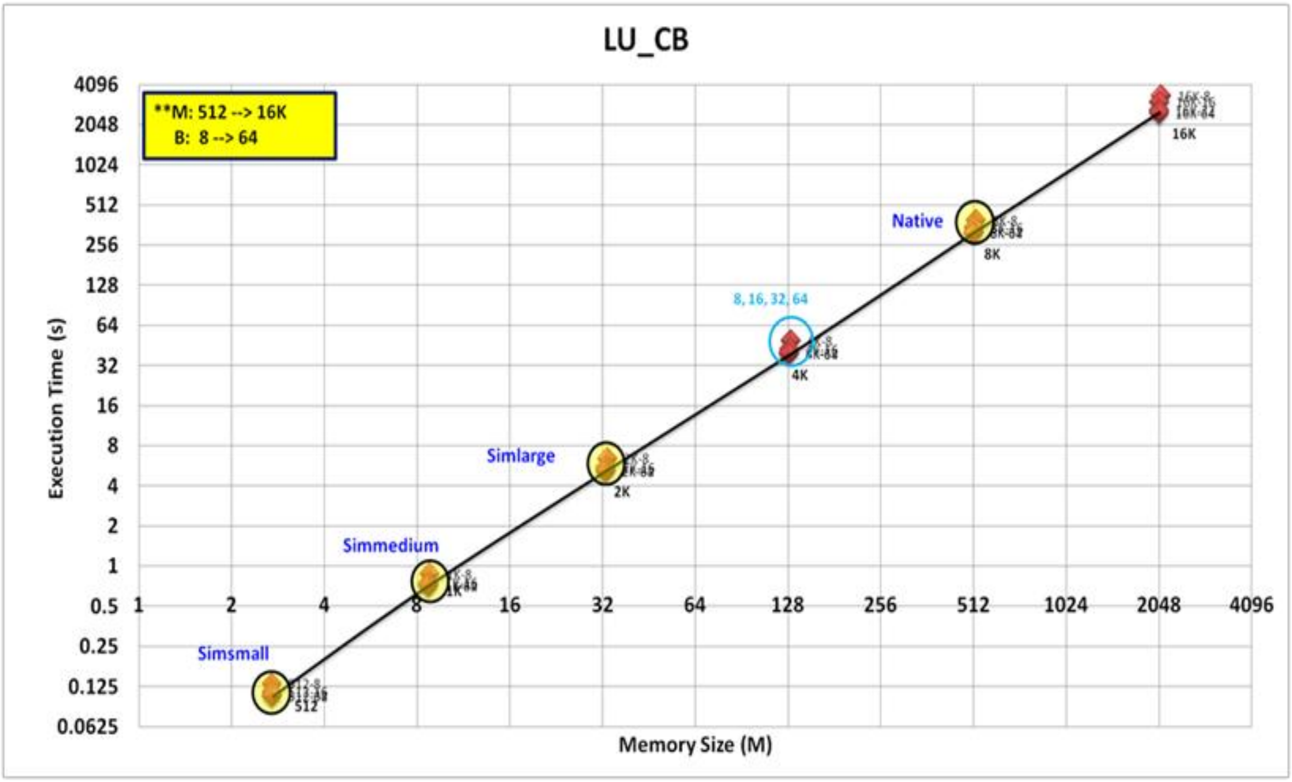
$$(p_1, p_2, \ldots, p_n)=F^{-1}(T, M) \quad (2),$$ where T is execution time, M is memory size, and p_i is input parameter.

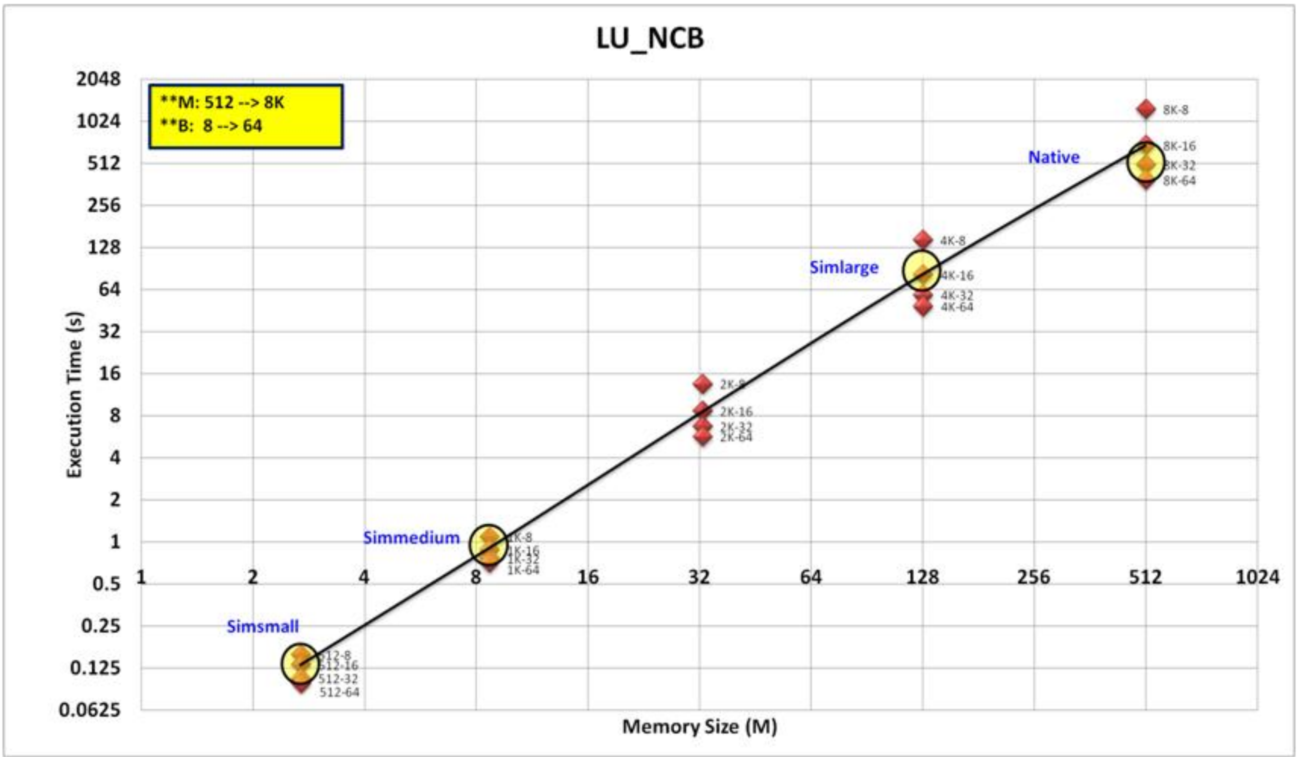





FFT
**M: 18 -> 28
Native
Simlarge
Simmedium
Simsmall
18
20
22
24
26
28
Execution Time (s)
256
128
64
32
16
8
4
2
1
0.5
0.25
0.125
0.0625
4
8
16
32
64
128
256
512
1024
2048
4096
8192
16384
Memory Size (M)


FMM
Cluster: One, Two
**Total_Particles: 1K --> 4M
**Time Steps: 5 --> 15
Native
Simlarge
Simmedium
Simsmall
One Cluster
Two Cluster
1C-4M-10
2C-4M-5
4M
2C-1M-10
2C-1M-5
1M
2K
2C-512K-15
512K
15
10
2C-256K-15
2C-256K-5
256K
2C-128K-15
128K
2C-64K-15
2C-64K-5
64K
2C-32K-15
32K
2C-16K-15
16K
2C-8K-5
8K
2C-4K-5
4K
1C-2K-5
2K
2C-1K-5
1K
Execution Time (s)
512
256
128
64
32
16
8
4
2
1
0.5
0.25
0.125
0.0625
0.03125
1
2
4
8
16
32
64
128
256
512
1024
2048
4096
Memory Size (M)


LU_CB
**M: 512 --> 16K
B: 8 --> 64
Execution Time (s)
Memory Size (M)
Simsmall
Simmedium
Simlarge
8, 16, 32, 64
Native
512
2K
4K
8K
16K


LU_NCB
**M: 512 --> 8K
**B: 8 --> 64
Execution Time (s)
Memory Size (M)
Simsmall
Simmedium
Simlarge
Native
512-8
512-16
512-32
512-64
1K-8
1K-16
1K-32
1K-64
2K-16
2K-32
2K-64
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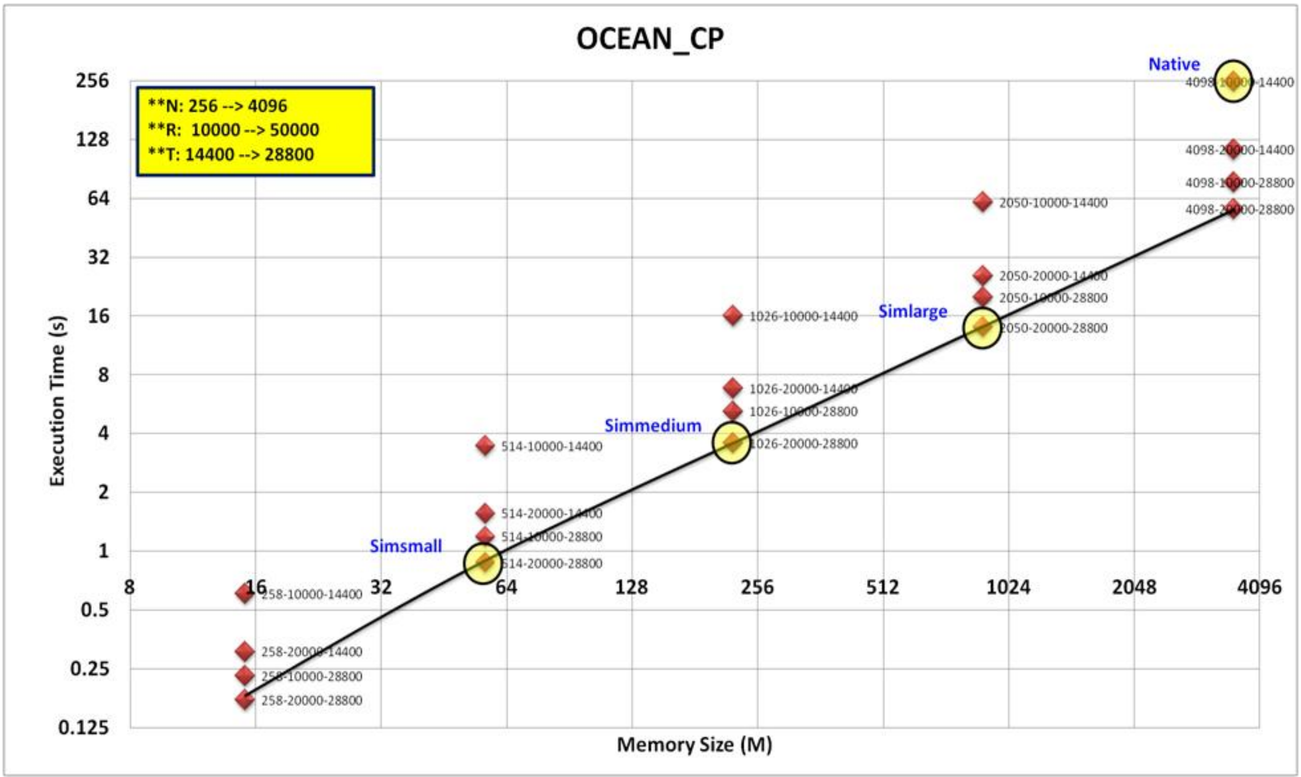
8K-32
8K-64


OCEAN_CP
**N: 256 --> 4096
**R: 10000 --> 50000
**T: 14400 --> 28800
Native
Simlarge
Simmedium
Simsmall
Execution Time (s)
Memory Size (M)
4098-10000-14400
4098-20000-14400
4098-10000-28800
4098-20000-28800
2050-10000-14400
2050-20000-14400
2050-10000-28800
2050-20000-28800
1026-10000-14400
1026-20000-14400
1026-10000-28800
1026-20000-28800
514-10000-14400
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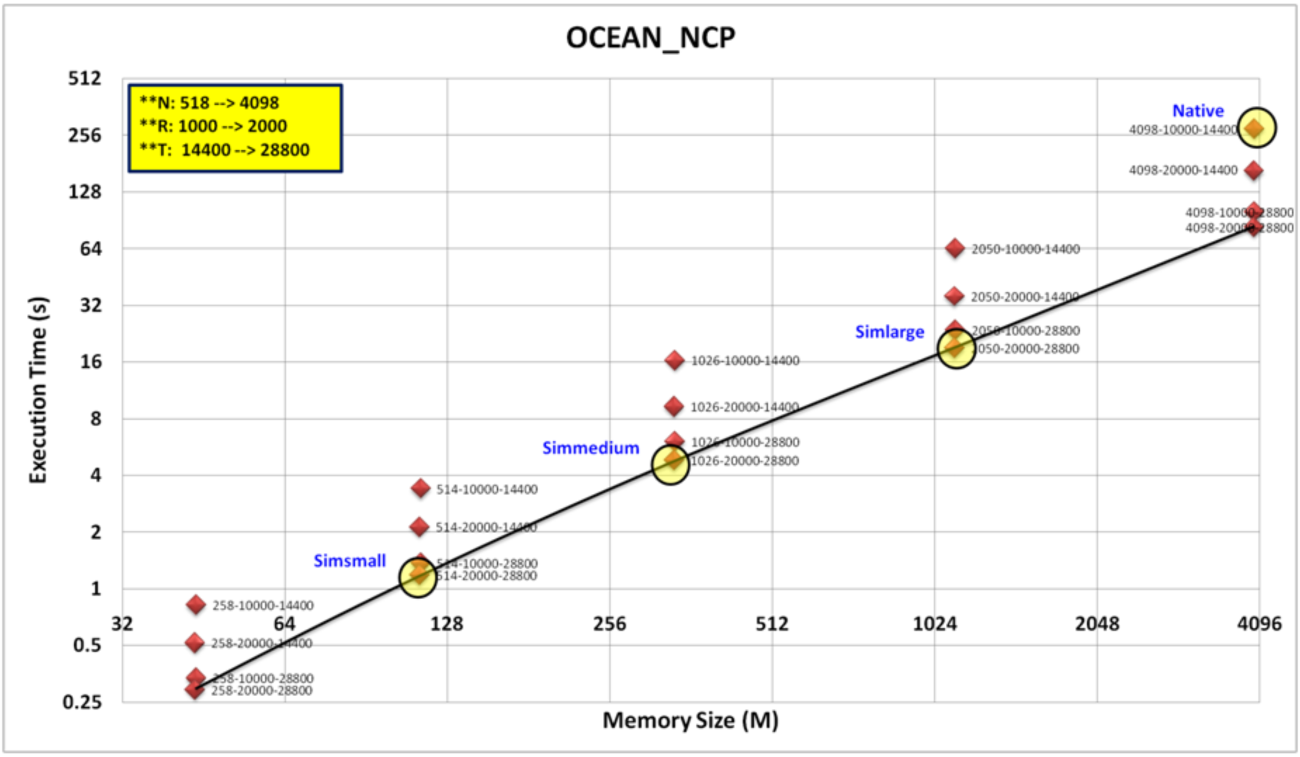
258-10000-28800
258-20000-28800


OCEAN_NCP
**N: 518 --> 4098
**R: 1000 --> 2000
**T: 14400 --> 28800
Native
Simlarge
Simmedium
Simsmall
Execution Time (s)
Memory Size (M)
4098-10000-14400
4098-20000-14400
4098-10000-28800
4098-20000-28800
2050-10000-14400
2050-20000-14400
2050-10000-28800
2050-20000-28800
1026-10000-14400
1026-20000-14400
1026-10000-28800
1026-20000-28800
514-10000-14400
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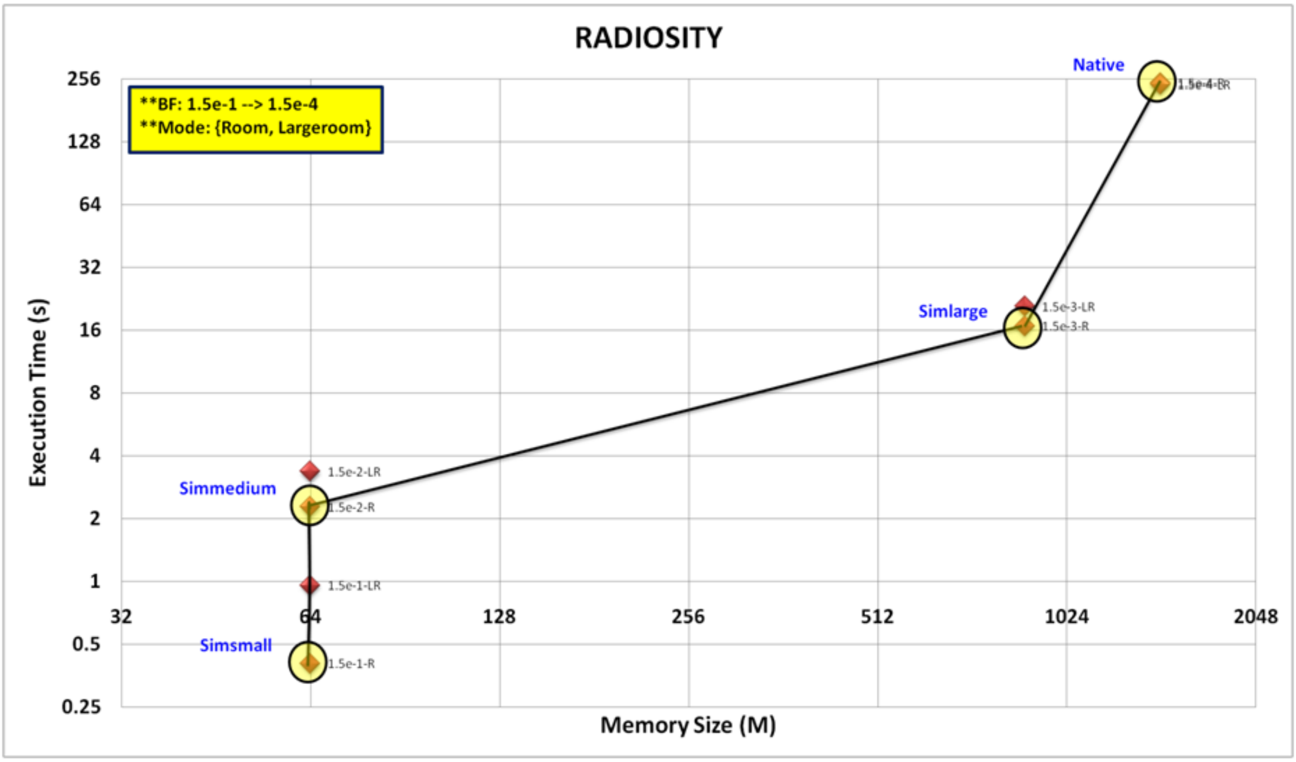
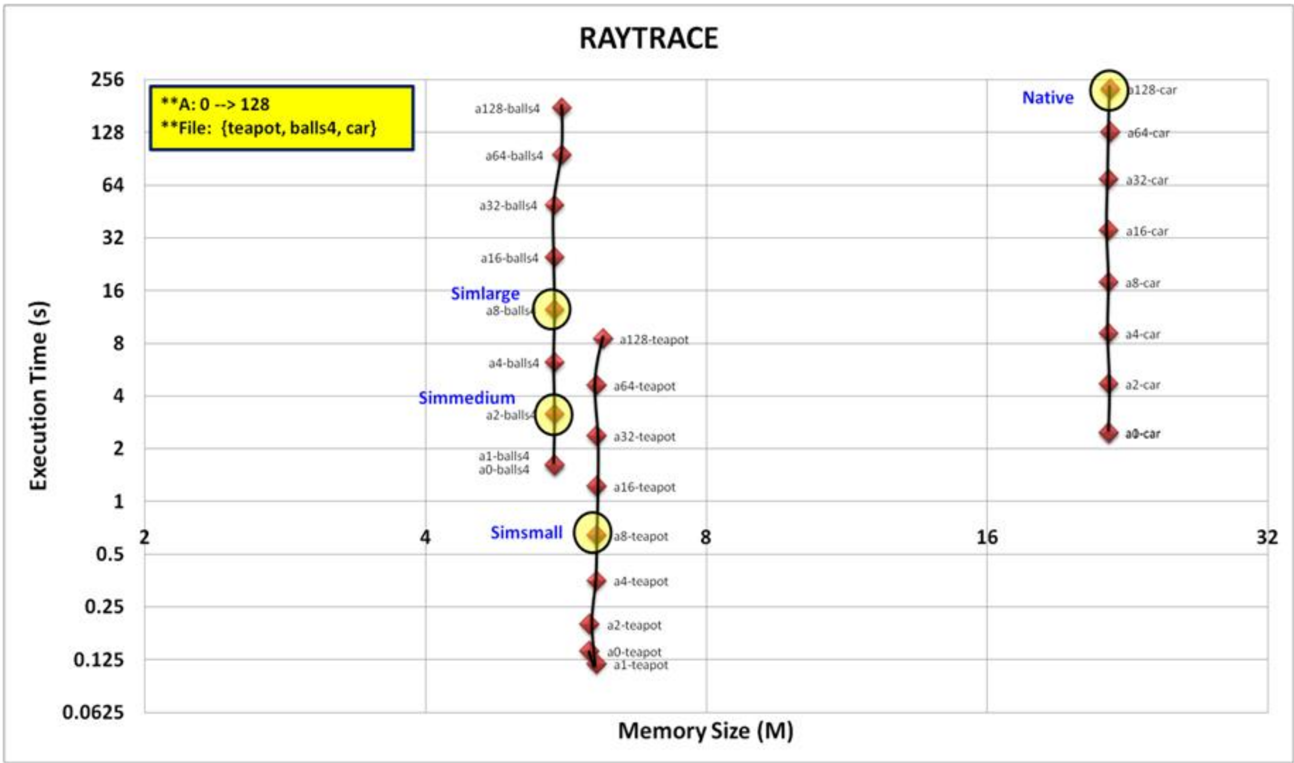
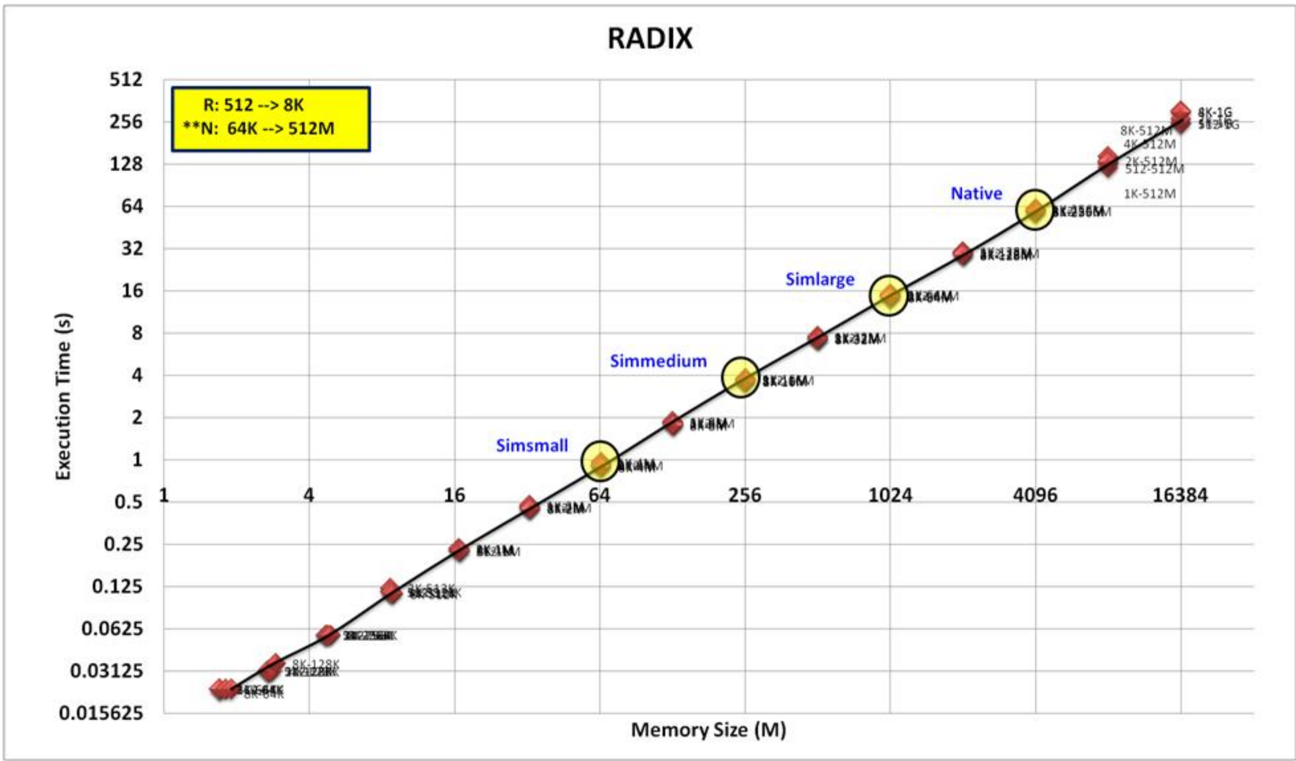

RADIOSITY
**BF: 1.5e-1 --> 1.5e-4
**Mode: {Room, Largeroom}
Native
Simlarge
Simmedium
Simsmall
1.5e-2-LR
1.5e-2-R
1.5e-1-LR
1.5e-1-R
1.5e-3-LR
1.5e-3-R
Execution Time (s)
Memory Size (M)
256
128
64
32
16
8
4
2
1
0.5
0.25
32
64
128
256
512
1024
2048


RAYTRACE
**A: 0 --> 128
**File: {teapot, balls4, car}
Native
Simlarge
Simmedium
Simsmall
a128-balls4
a64-balls4
a32-balls4
a16-balls4
a8-balls4
a4-balls4
a2-balls4
a1-balls4
a0-balls4
a128-teapot
a64-teapot
a32-teapot
a16-teapot
a8-teapot
a4-teapot
a2-teapot
a0-teapot
a1-teapot
a128-car
a64-car
a32-car
a16-car
a8-car
a4-car
a2-car
a0-car
Execution Time (s)
Memory Size (M)
256
128
64
32
16
8
4
2
1
0.5
0.25
0.125
0.0625
2
4
8
16
32


RADIX
R: 512 --> 8K
**N: 64K --> 512M
Execution Time (s)
Memory Size (M)
512
256
128
64
32
16
8
4
2
1
0.5
0.25
0.125
0.0625
0.03125
0.015625
1
4
16
64
256
1024
4096
16384
Native
Simlarge
Simmedium
Simsmall
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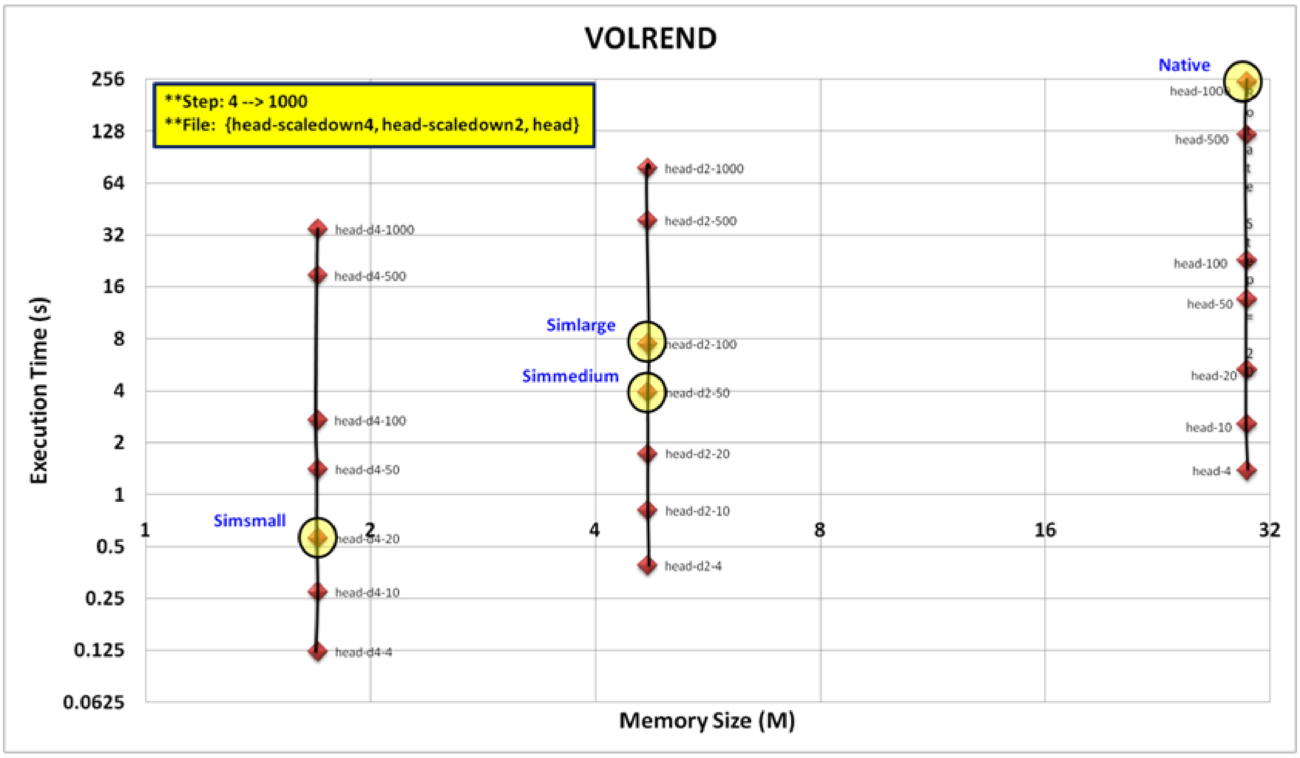
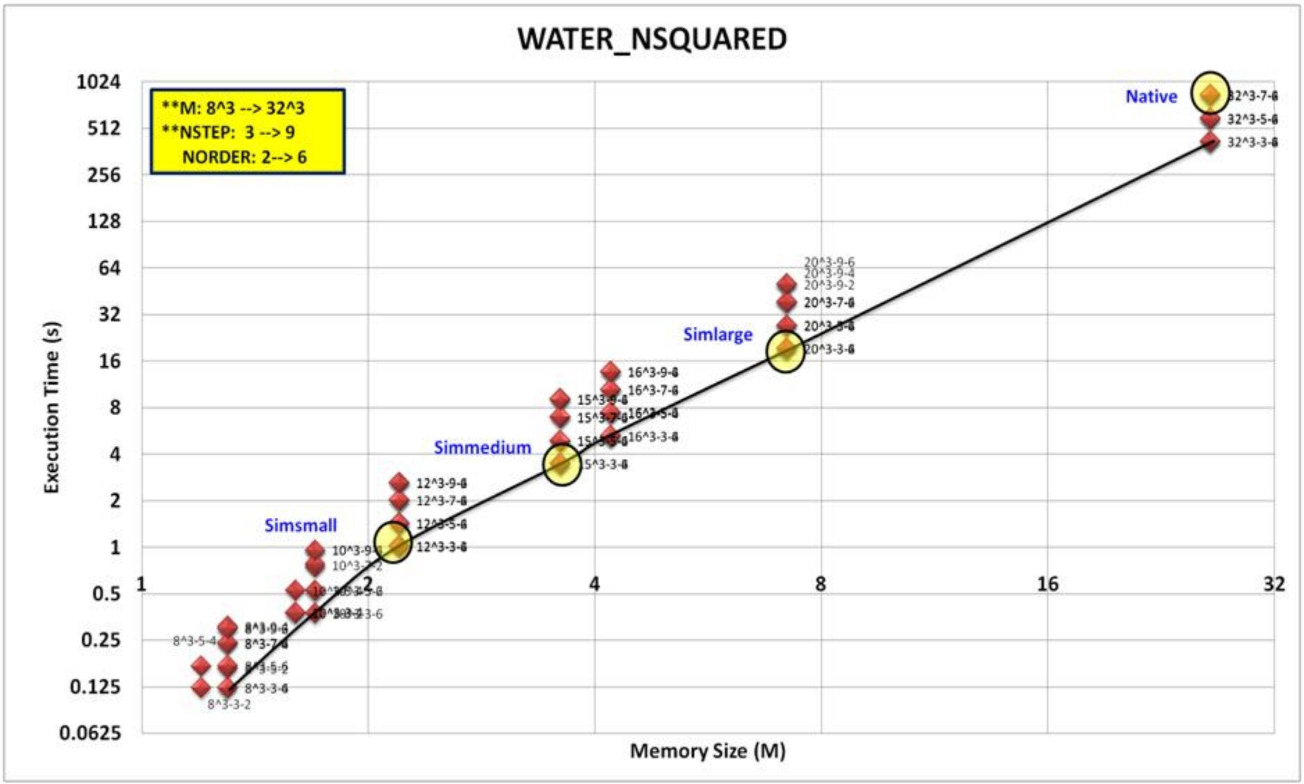
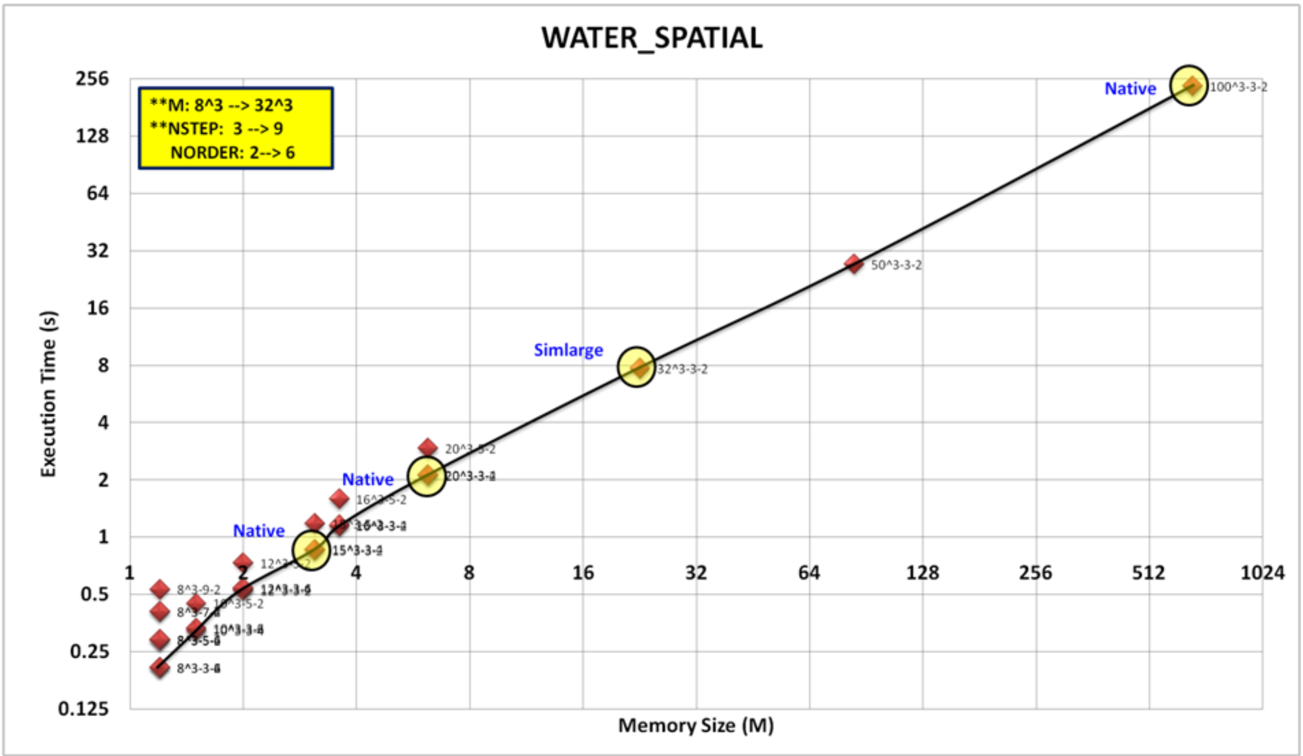
1K-512M
8K-128K


VOLREND
**Step: 4 --> 1000
**File: {head-scaledown4, head-scaledown2, head}
Execution Time (s)
Memory Size (M)
256
128
64
32
16
8
4
2
1
0.5
0.25
0.125
0.0625
1
2
4
8
16
32
Native
Simlarge
Simmedium
Simsmall
head-1000
head-500
head-100
head-50
head-20
head-10
head-4
head-d2-1000
head-d2-500
head-d2-100
head-d2-50
head-d2-20
head-d2-10
head-d2-4
head-d4-1000
head-d4-500
head-d4-100
head-d4-50
head-d4-20
head-d4-10
head-d4-4


WATER_NSQUARED
**M: 8^3 --> 32^3
**NSTEP: 3 --> 9
NORDER: 2--> 6
Native
Simlarge
Simmedium
Simsmall
32^3-7-6
32^3-5-6
32^3-3-6
20^3-9-6
20^3-9-4
20^3-9-2
20^3-7-6
20^3-3-6
16^3-9-6
16^3-7-6
16^3-3-6
12^3-9-6
12^3-7-6
12^3-3-6
8^3-5-4
8^3-9-6
8^3-7-6
8^3-3-6
8^3-3-2
1024
512
256
128
64
32
16
8
4
2
1
0.5
0.25
0.125
0.0625
1
2
4
8
16
32
Execution Time (s)
Memory Size (M)


WATER_SPATIAL
**M: 8^3 --> 32^3
**NSTEP: 3 --> 9
NORDER: 2--> 6
Native
Simlarge
Native
Native
100^3-3-2
50^3-3-2
32^3-3-2
20^3-5-2
16^3-5-2
15^3-3-2
12^3-3-6
8^3-9-2
10^3-5-2
10^3-3-6
8^3-3-6
256
128
64
32
16
8
4
2
1
0.5
0.25
0.125
1
2
4
8
16
32
64
128
256
512
1024
Execution Time (s)
Memory Size (M)