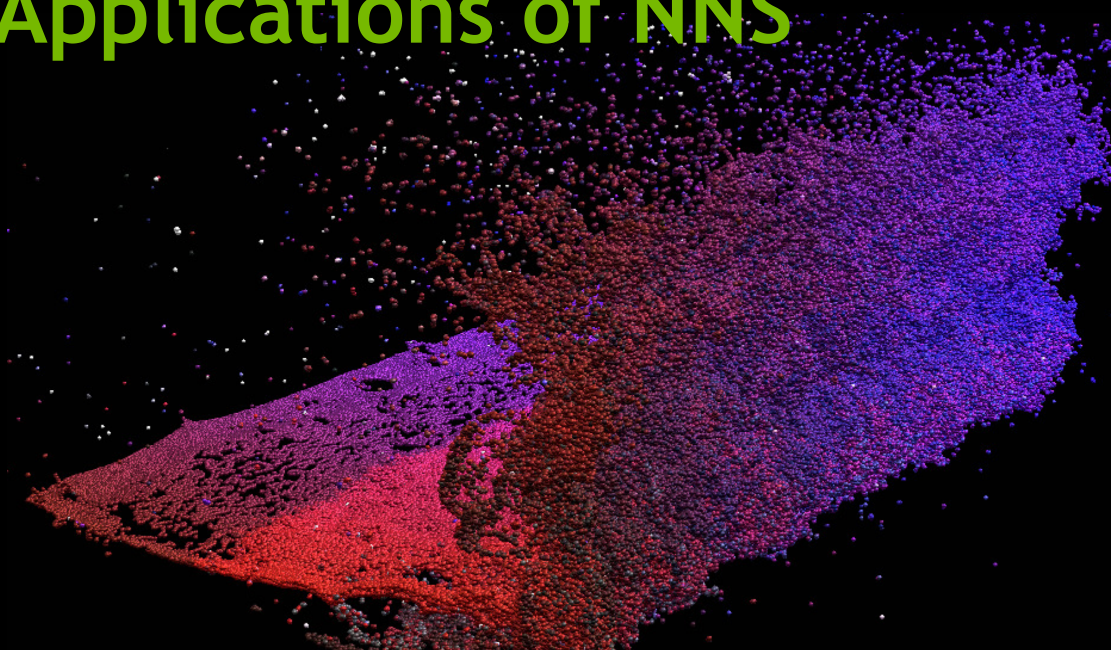
GPU TECHNOLOGY CONFERENCE

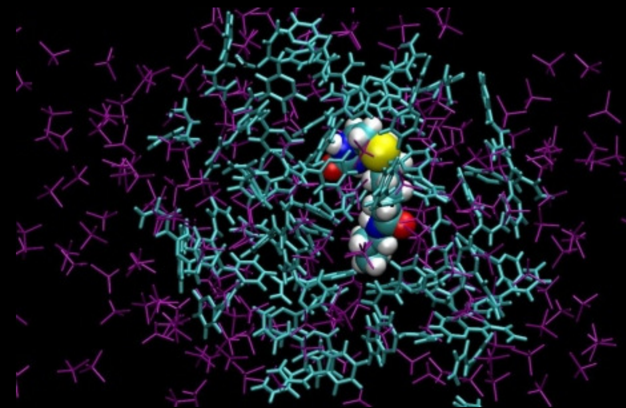
FAST FIXED-RADIUS NEAREST NEIGHBORS: INTERACTIVE MILLION-PARTICLE FLUIDS

Rama C. Hoetzlein, Graphics Devtech, NVIDIA

Applications of NNS



Fluid Simulation

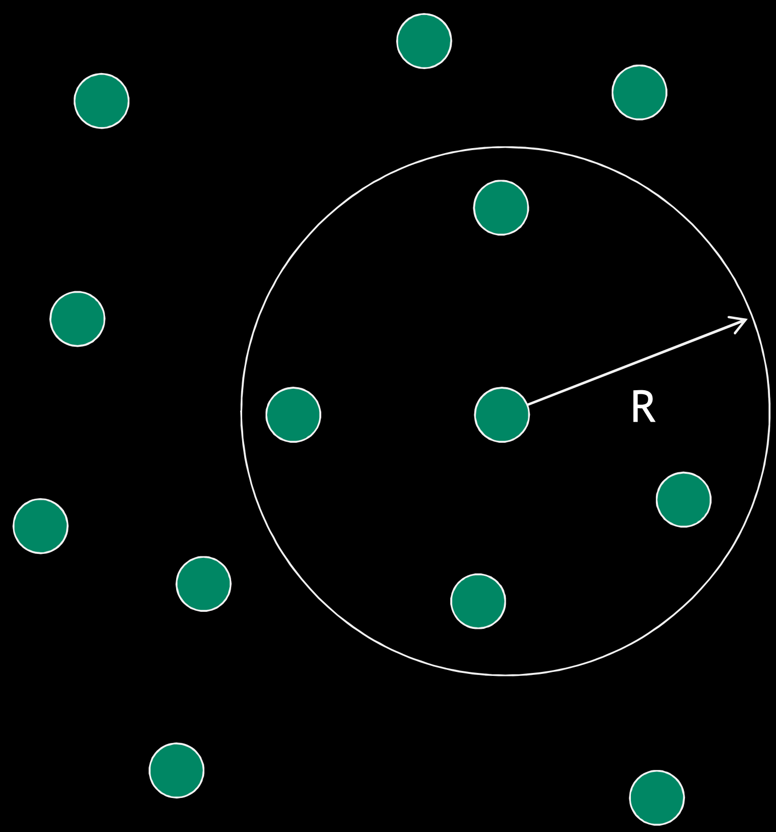


Molecular Modeling

Cognitive Science – Behavioral simulation

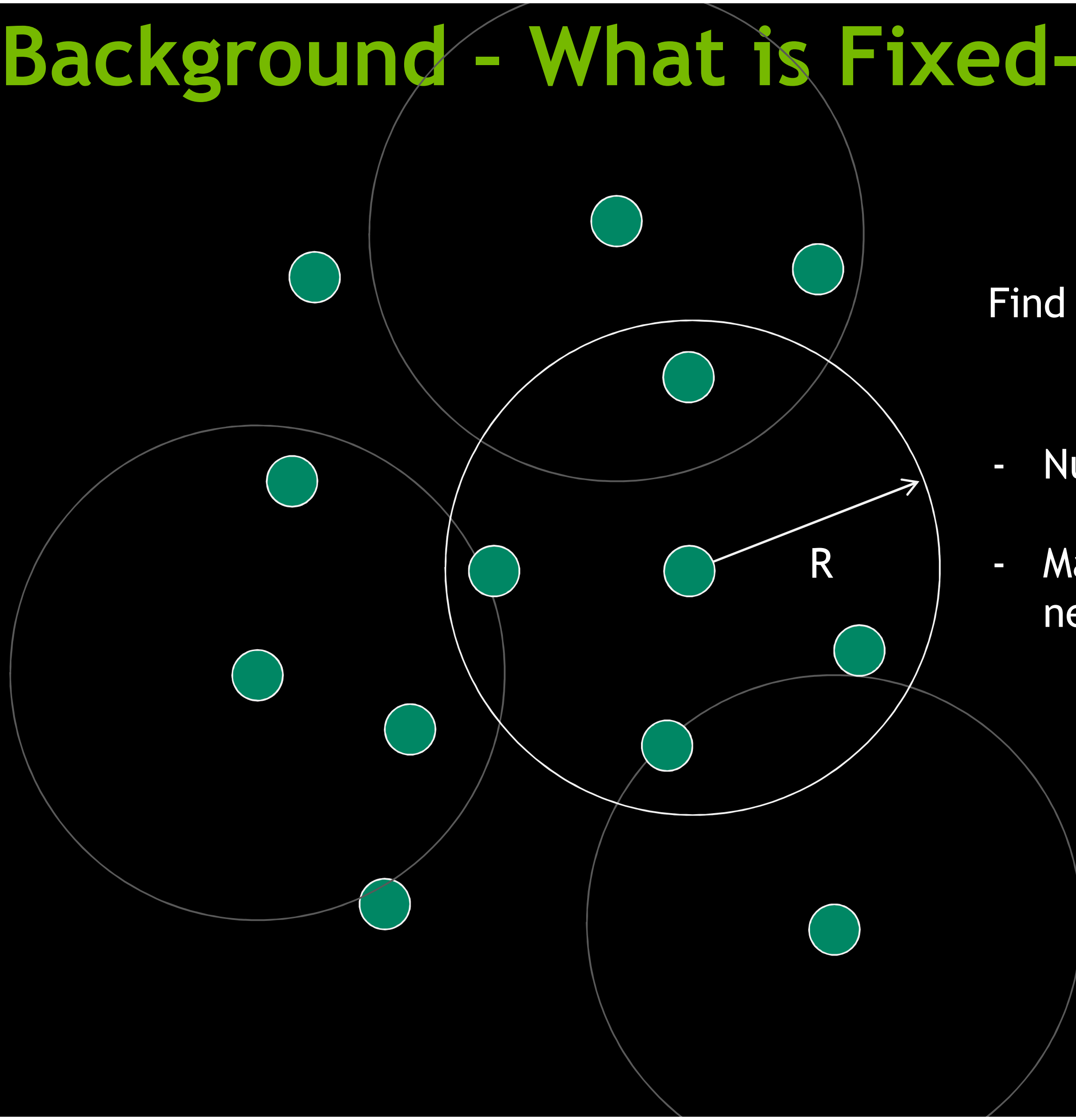
3D Scanning - Point Cloud Reconstruction

Background - What is Fixed-Radius NNS?



Find all neighbors in a fixed radius R

Background - What is Fixed-Radius NNS?

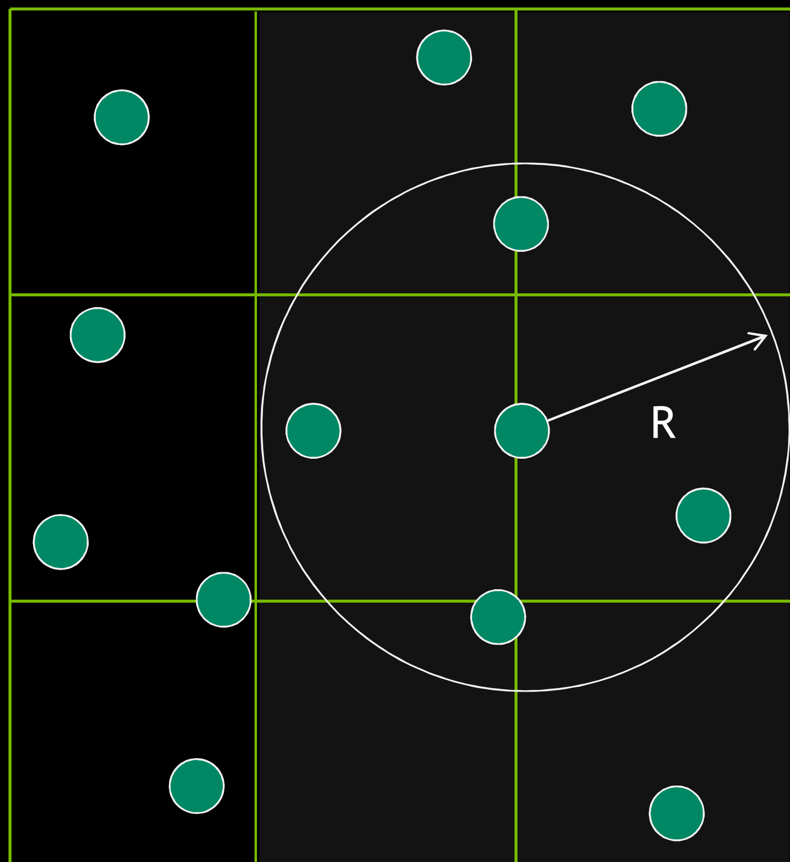


Find all neighbors in a fixed radius R

- Number of neighbors may vary
- May need to find all fixed-radius neighbors of all particles

O (n^2)   brute force

Overall Strategy



Spatial Partitioning:

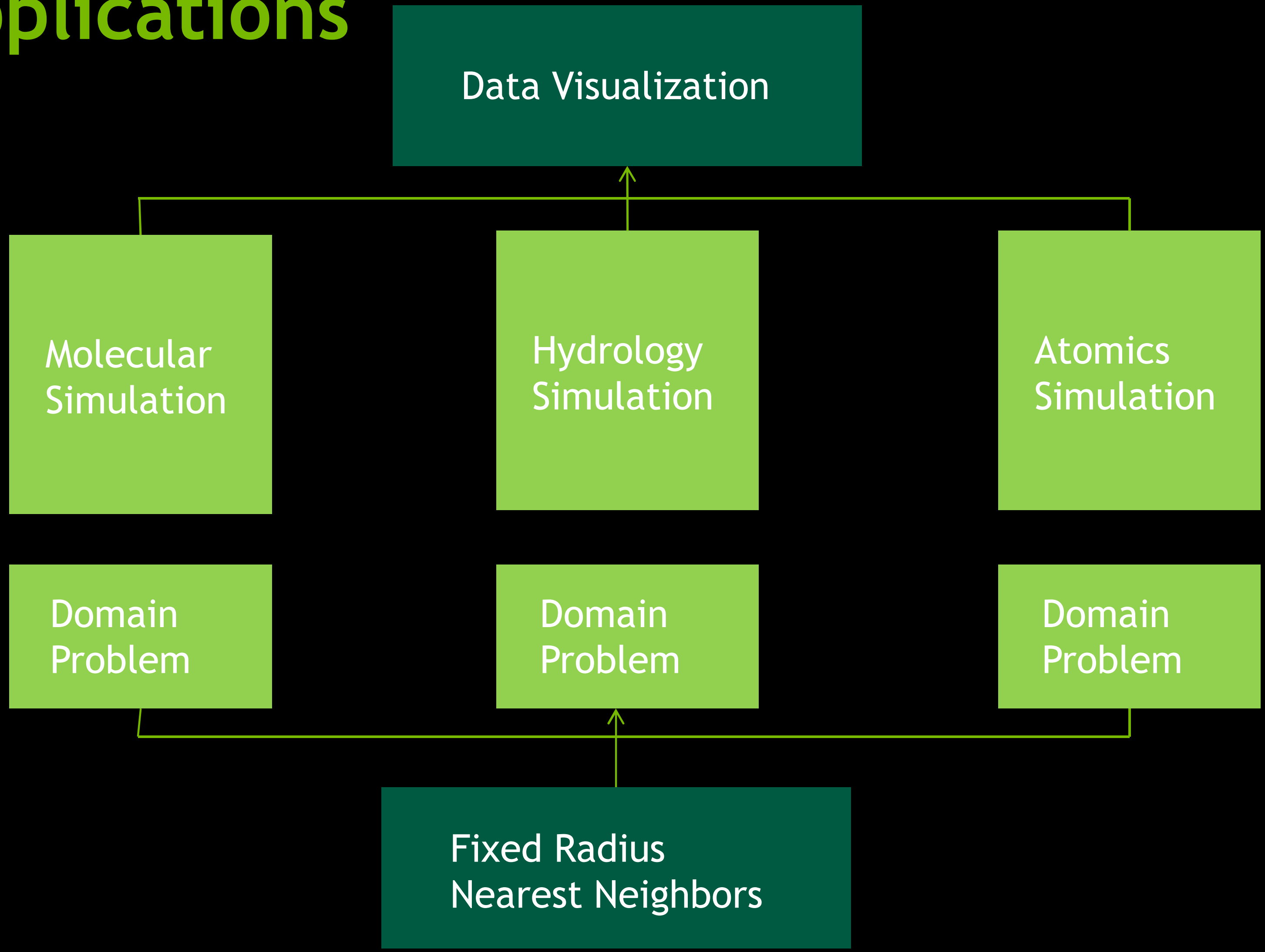
1. Partition space equally into bins

2. Insert each particle into bins

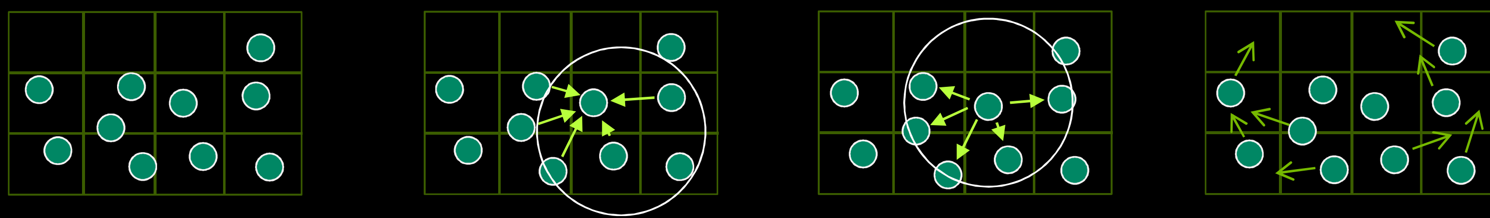
3. Only need to search particles found in neighboring bins

O (N k)

Applications



Applications - Example



Insert Particles	Compute Pressures	Compute Forces	Integration (Advance)
Add to bins	Find neighbors / Compute P	Find neighbors / Compute F	Move particles
$O(N)$	$O(\ N(k+D_1)\ )$	$O(\ N(k+D_2)\ )$	$O(N * D_3)$

Nearest Neighbor Search

Domain Specific Cost

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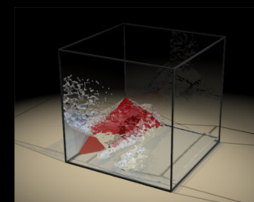
Research Background

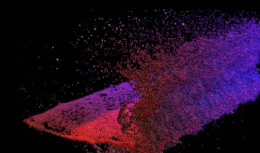
Fluid Simulation

2003 Muller
Particle-Based Fluid Simulation for Interactive Apps (SPH)

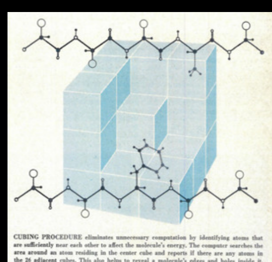


2009 Solenthaler
Predictor-Corrector (PCISPH)

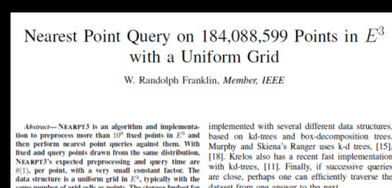
2013 Macklin & Muller
Position Based Fluids



Fluids v.3 (SPH)



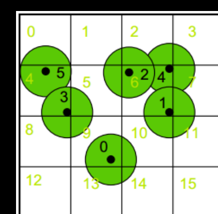
1966 Levinthal
Molecular-Model Building by Computer "Cubing" method



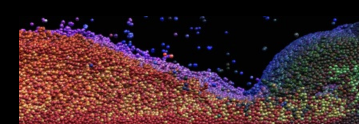
Nearest Point Query on 184,088,599 Points in E^3 with a Uniform Grid

W. Randolph Franklin, *Member, IEEE*

2006 Randolph Franklin
Nearest Point Query on 184,088,599 Points in E^3 with a Uniform Grid.
CPU Grid Search



2010 Simon Green
Particle Simulation using CUDA
Parallel Radix Sort



2013 Hoetzlein
Parallel Counting Sort NNS

Nearest Neighbor Search

GPU-based NNS

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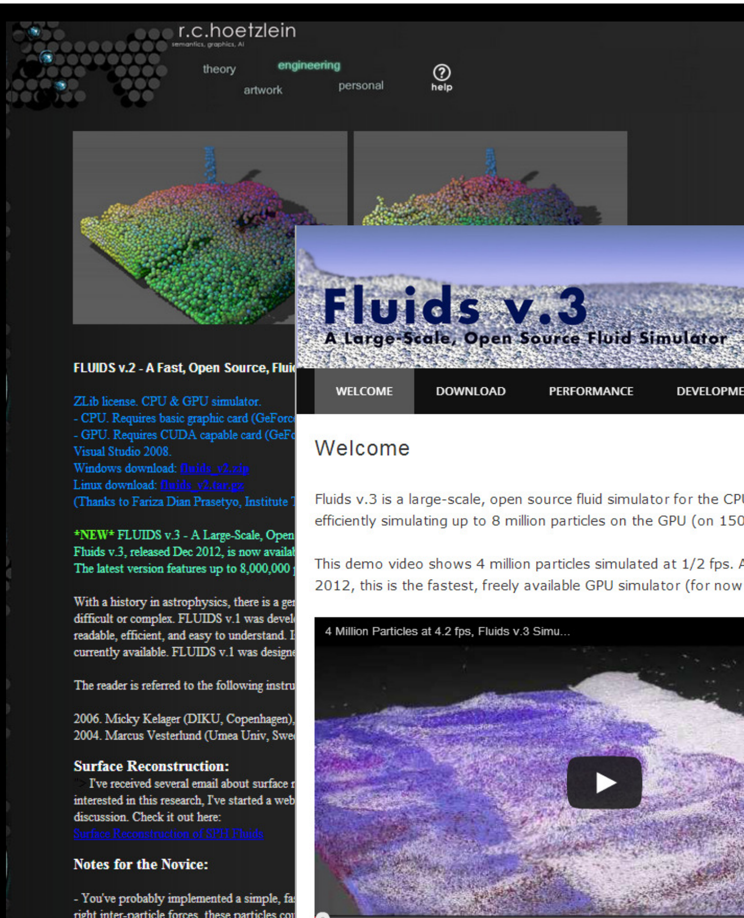
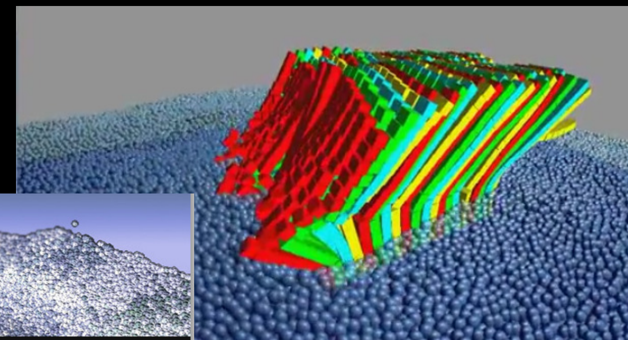


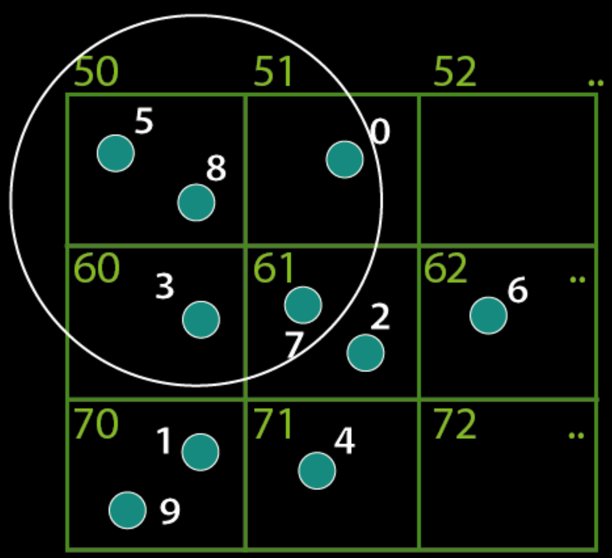


BULLET PHYSICS LIBRARY

Fluids v.3 http://fluids3.com

High Performance computing for scientific applications.
“Just the basics”, Zlib license, Research & Education, Solves NNS

Grid Search



Original Input

0	1	2	3	4	5	6	7	8	9
51	70	61	60	71	50	62	61	50	70

Neighboring Bins

50 51 60 61

0	1	2	3	4	5	6	7	8	9
51	70	61	60	71	50	62	61	50	70

SLOW - SCATTERED READS

Ideal Layout - Sorted by bins

5	8	0	3	7	2	6	1	9	4
50	50	51	60	61	61	62	70	70	71

Neighboring Bins

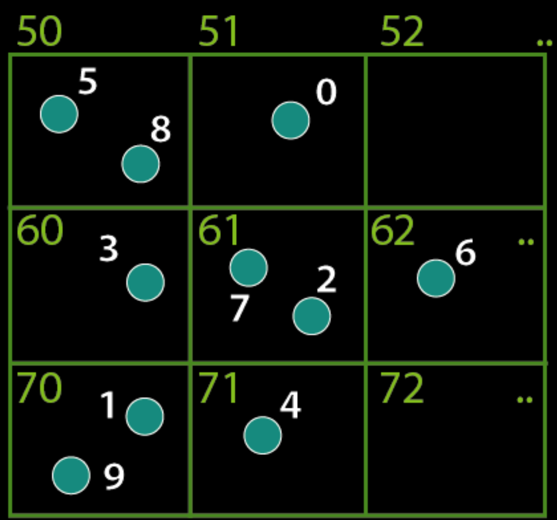
50 51 60 61

5	8	0	3	7	2	6	1	9	4
50	50	51	60	61	61	62	70	70	71

COHERENT READS !

Radix Sort

Previous method (Green 2008)



Input

0	1	2	3	4	5	6	7	8	9
51	70	61	60	71	50	62	61	50	70

Radix Sort

Digit 0

0	1	2	3	4	5	6	7	8	9
51	70	61	60	71	50	62	61	50	70

0 = 5   1 = 4   2 = 1

70	60	50	50	70	51	61	71	61	62

Digit 1

0	1	2	3	4	5	6	7	8	9
70	60	50	50	70	51	61	71	61	62

5 = 3   6 = 4   7 = 3

50	50	51	60	61	61	62	70	70	71

Repeat step for each digit in key

Output

5	8	0	3	7	2	6	1	9	4
50	50	51	60	61	61	62	70	70	71

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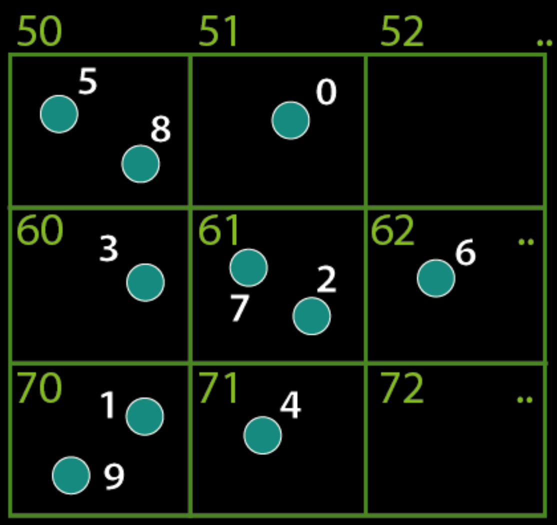
Counting Sort

Input

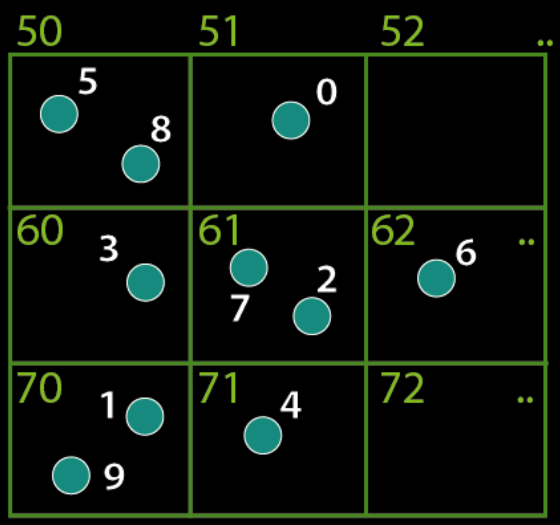
0	1	2	3	4	5	6	7	8	9
51	70	61	60	71	50	62	61	50	70



Observations:

1. Goal is to sort by bin
2. Position inside bin in irrelevant
3. Therefore, many duplicate keys
4. Better to perform 1-radix on exact bins, rather than on digits.

Counting Sort



Input

0	1	2	3	4	5	6	7	8	9
51	70	61	60	71	50	62	61	50	70

Insert + Counts

0	1	2	3	4	5	6	7	8	9
51	70	61	60	71	50	62	61	50	70
1	1	1	1	1	1	1	2	2	2

50 = 2	60 = 1	70 = 2
51 = 1	61 = 2	71 = 1
52 = 0	62 = 1	72 = 0

Prefix Sum

50	50	51	60	61	61	62	70	70	71
0		2	3	4		6	7		9

Counting Sort

0	1	2	3	4	5	6	7	8	9
		1					2		
5	8	0	3	2	7	6	1	9	4
50	50	51	60	61	61	62	70	70	71

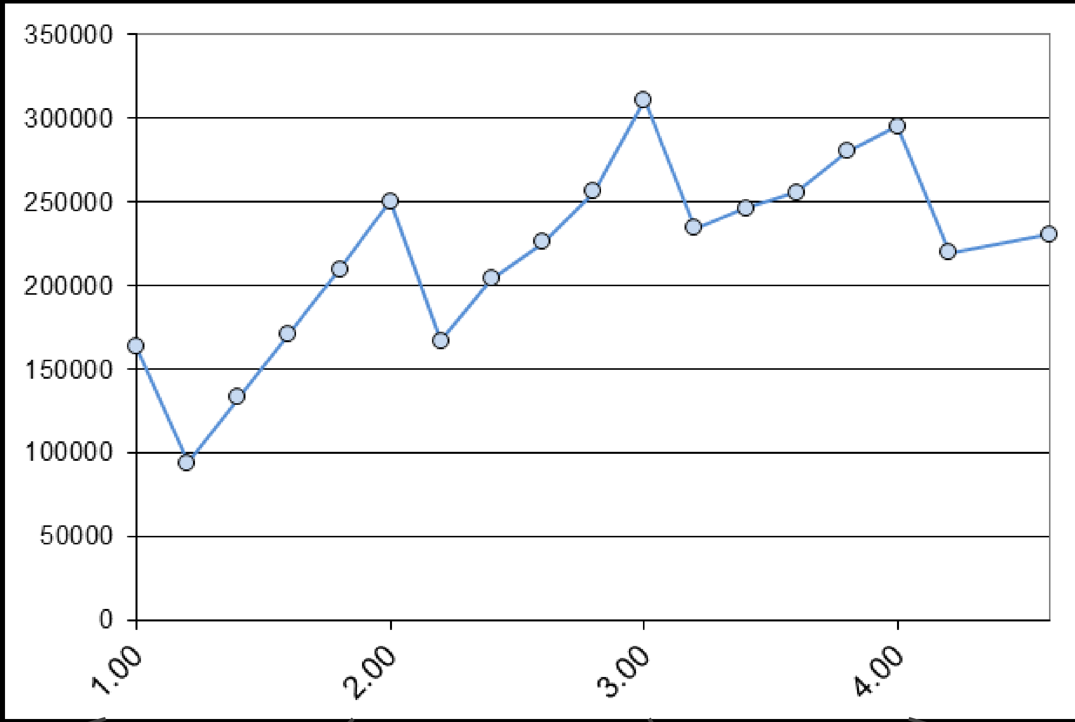
Output

5	8	0	3	2	7	6	1	9	4
50	50	51	60	61	61	62	70	70	71

What is a good Grid Cell Size?

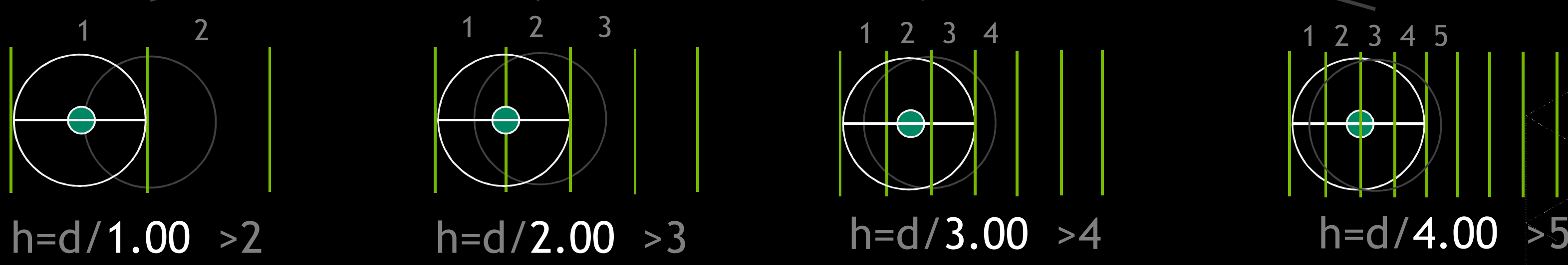
Too many particles per cell

e.g.
p = 200+ / cell



Too many grid cells to check

e.g.
5x5x5 = 125 cells



Algorithm Comparison

CUDA Particles (Radix Sort)

Insert Particles
- assign particle to cell

Sort Particles
- thrust:sort_by_key
- example: CUDA RadixSort
- for 1 to 4 (each byte in key)
  - Bin Counts
  - Bin Prefix Sum
  - RadixAddOffsetAndShuffle

Reindex (copy particles in order)

Time integration

Fluids v.3 (Counting Sort)

Insert Particles
- assign particle to cell

Sort Particles
  - Bin Sums
  - Bin Prefix Sum
  - ~~Radix Offset and Shuffle~~

ReIndex (copy particles in order)

Time integration

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Algorithm Comparison

CUDA Particles (Radix Sort)

1 Insert Particles
    assign particle to cell

Sort Particles
    thrust:sort_by_key
    example: CUDA RadixSort
    for 1 to 4 (each byte in key)
4   Bin Counts
4   Bin Prefix Sum
4   RadixAddOffsetAndShuffle

1 Reindex (copy particles in order)

1 Time integration

15 Kernel calls / Frame

Fluids v.3 (Counting Sort)

1 Insert Particles
    assign particle to cell
    AtomicAdd for Bin Counts & Indices

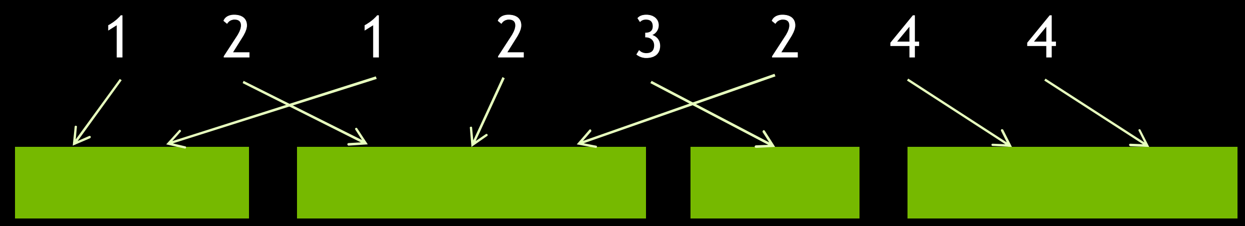
Sort Particles
        ~~Bin Sums~~
1   Bin Prefix Sum
        ~~Radix Offset and Shuffle~~

1 ReIndex (copy particles in order)

1 Time integration

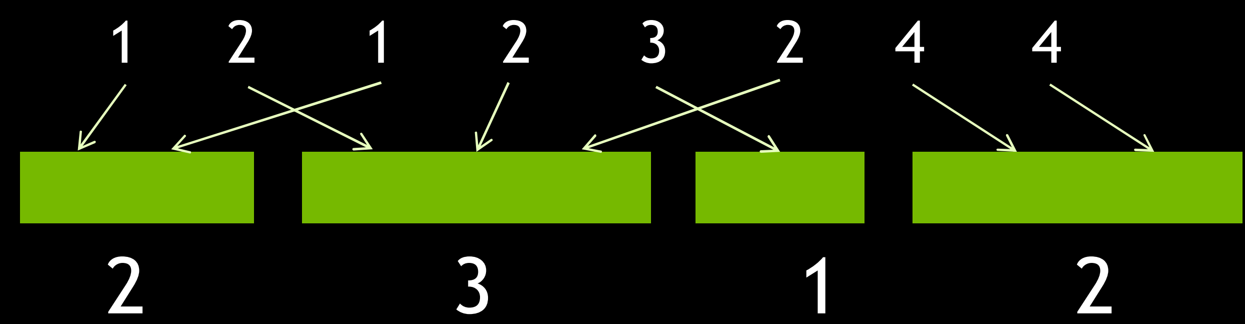
4 Kernel calls / Frame

Bin Counting



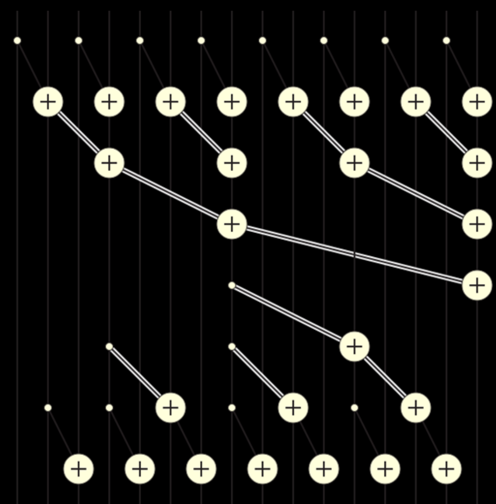
How many? 2 3 1 2

Bin Counting



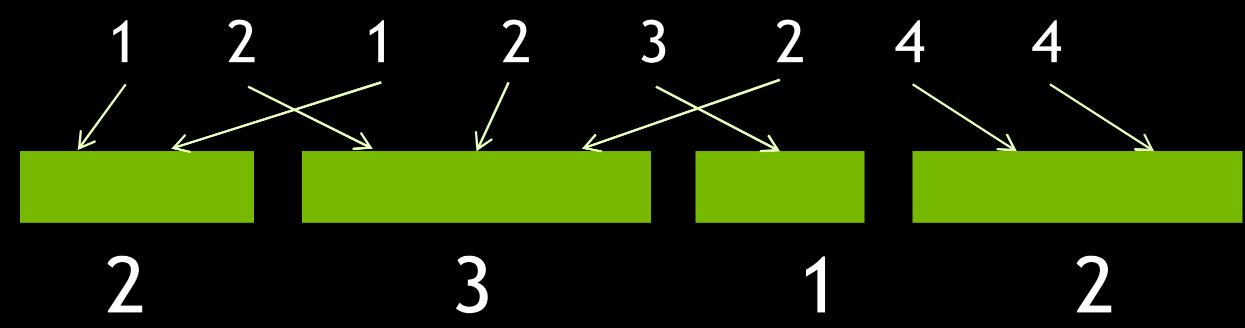
Old Method

Parallel Sums



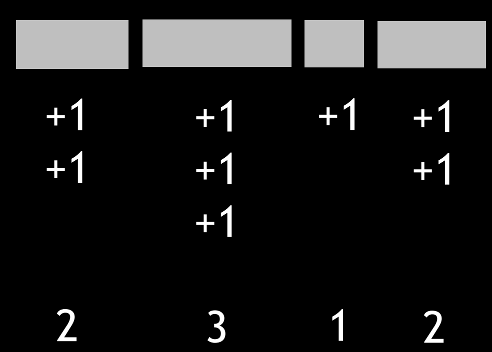
Each GPU thread computes binary sets of sums.

Bin Counting



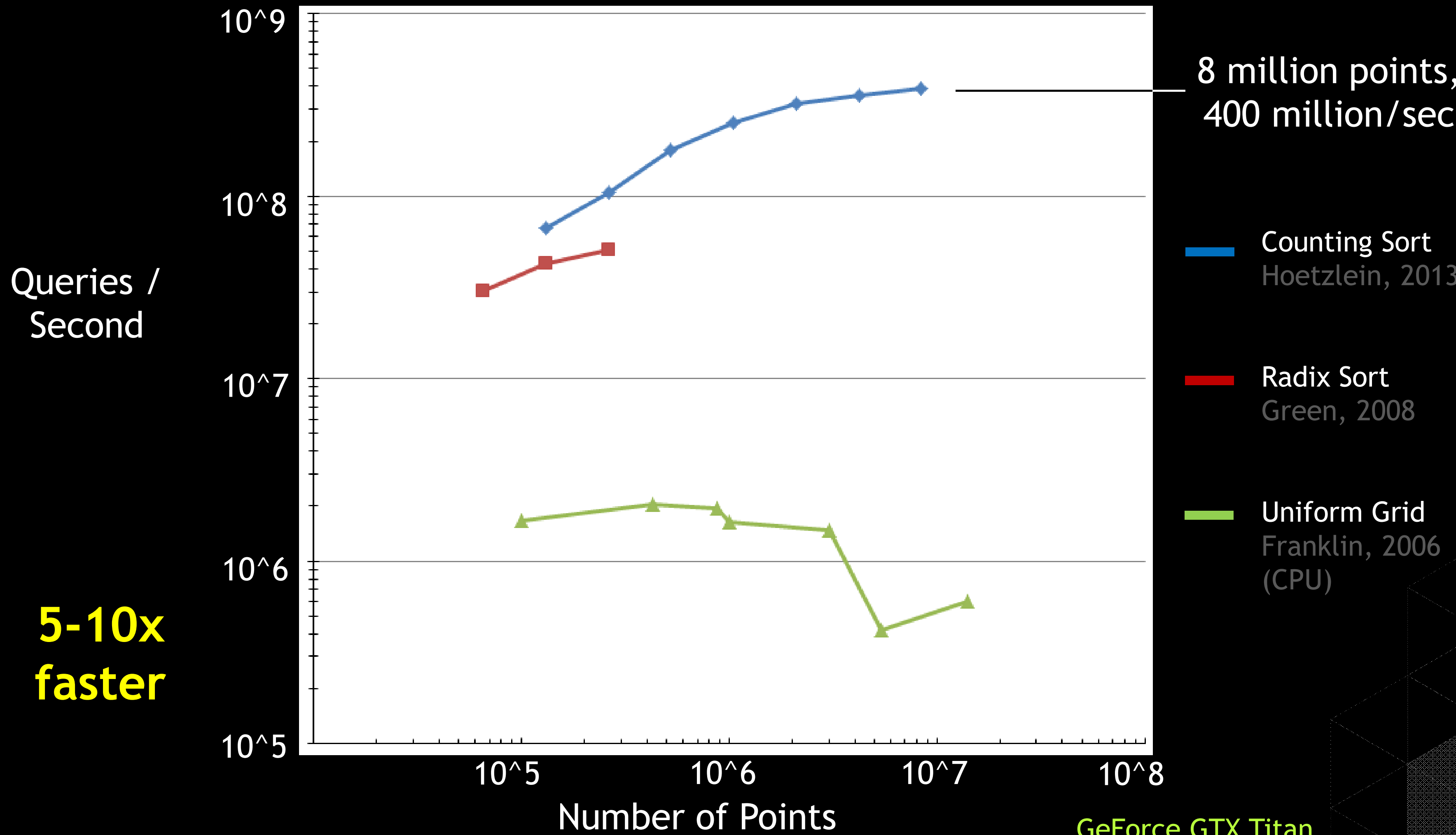
New Method

Atomic
Adds



Each particle
atomic-adds into bin
at the same time
bin is determined.

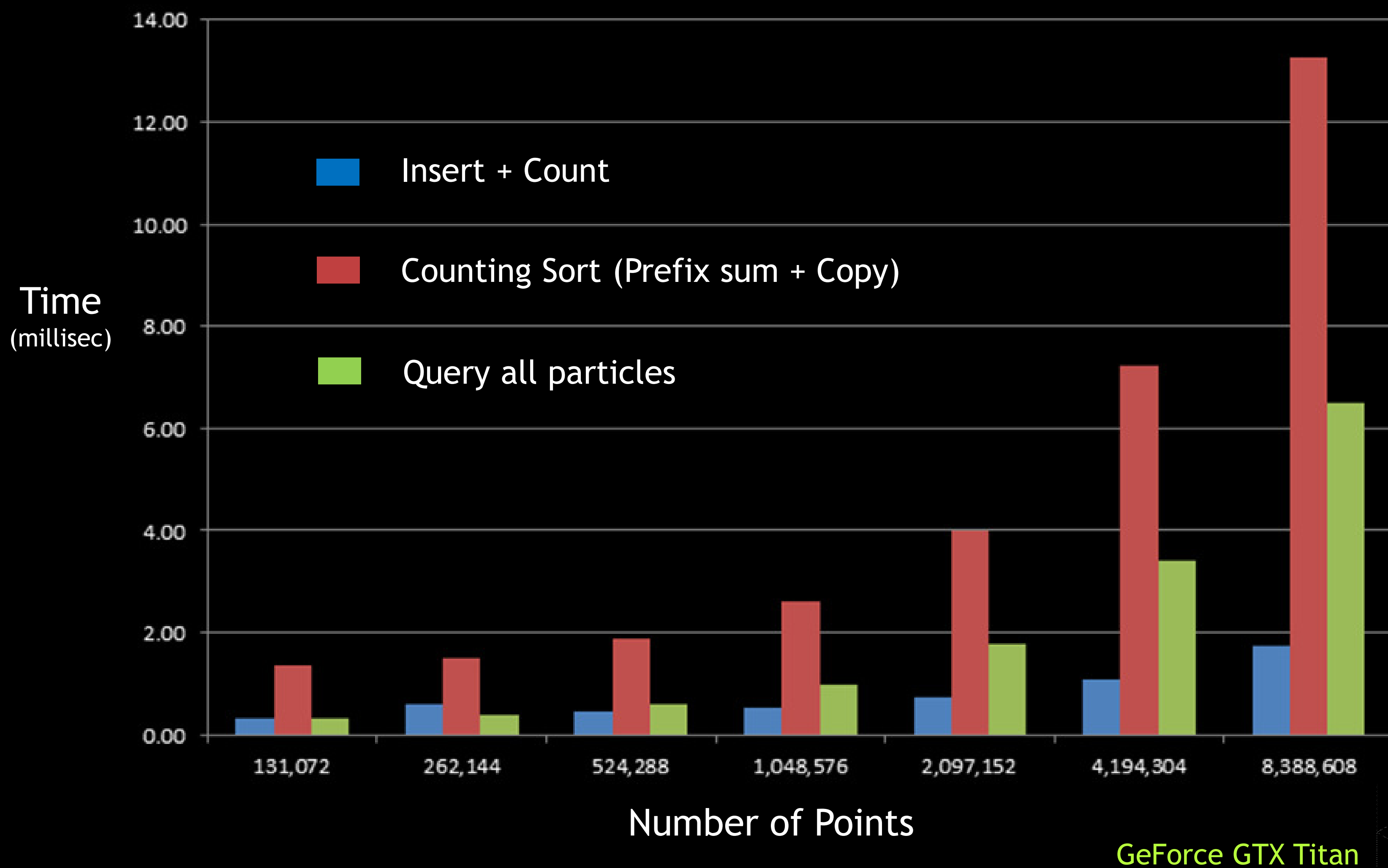
Results - Queries per Second



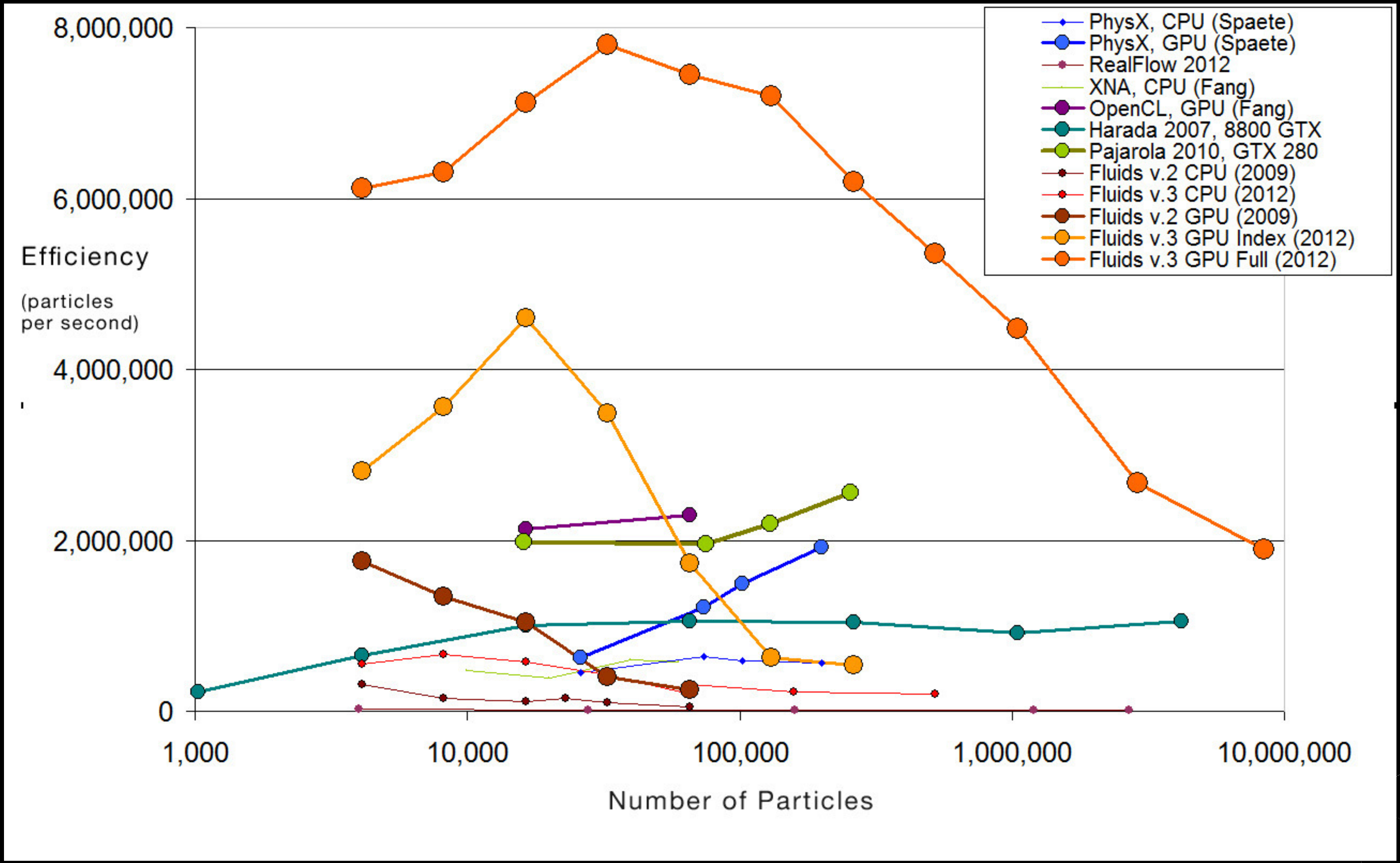
5-10x faster

GeForce GTX Titan

Results - Time for Each Step



Results - Fluids Example



** Results do not show fluid accuracy or time step.*

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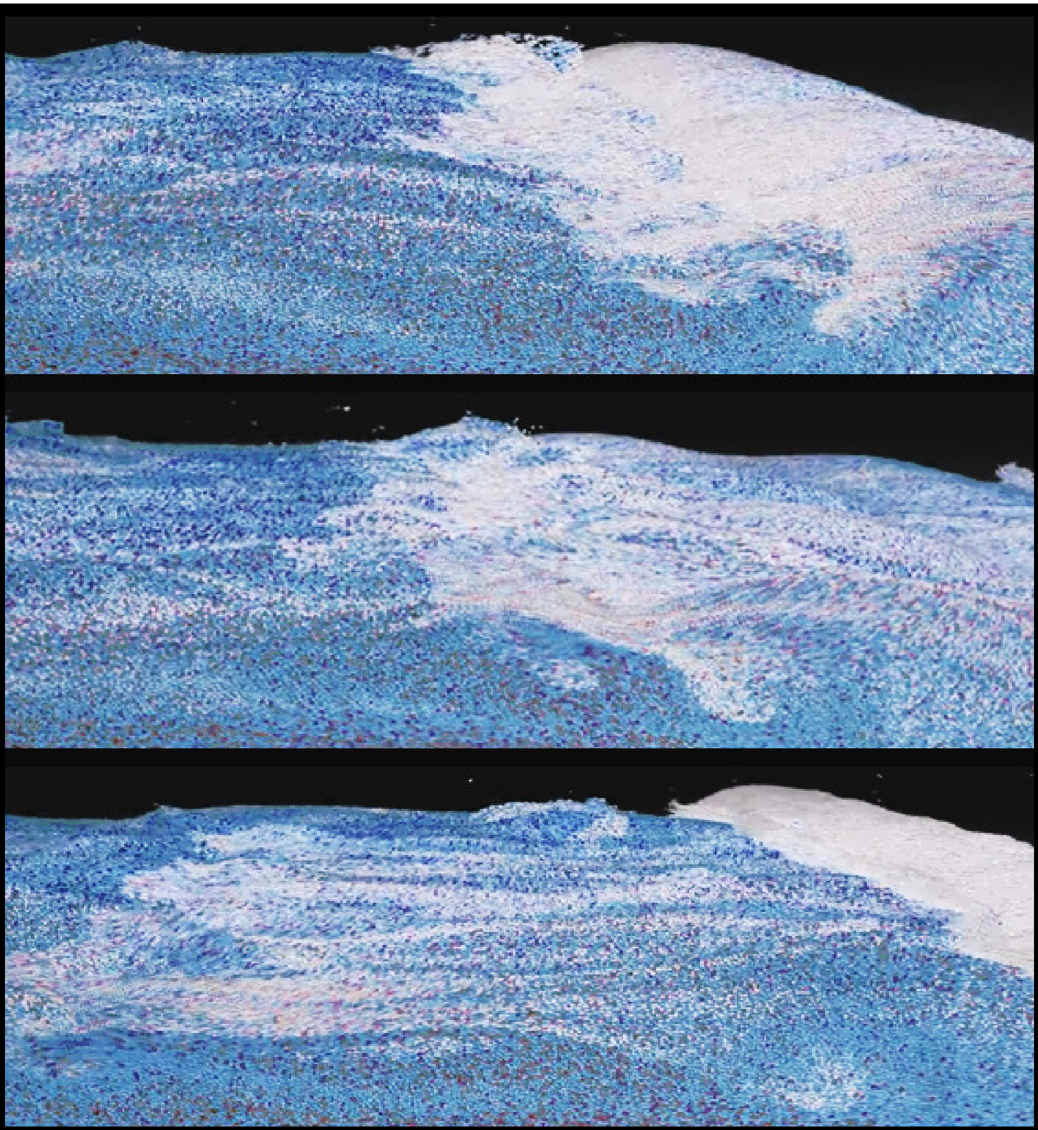
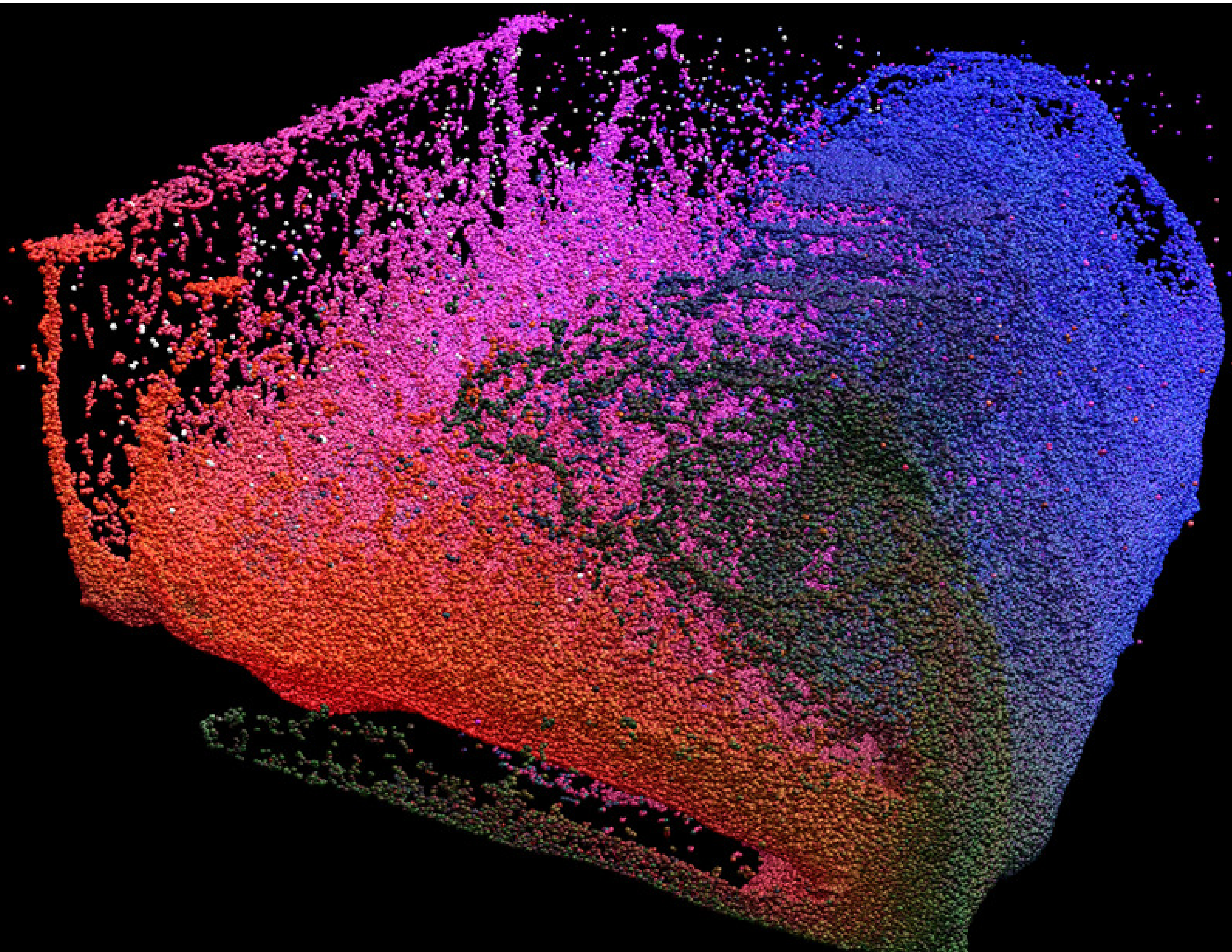
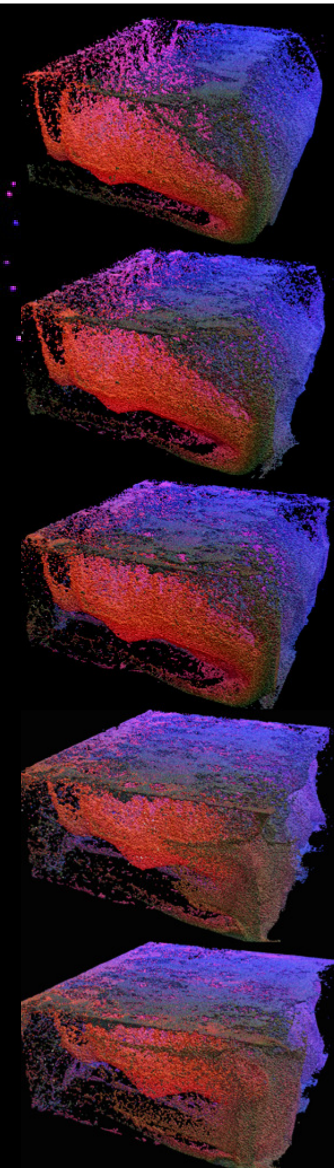


Continuous Ocean Simulation, 4.2 fps, 4,194,304 particles





Interactive Microgravity Simulation. 12 fps, 2,097,152 particles

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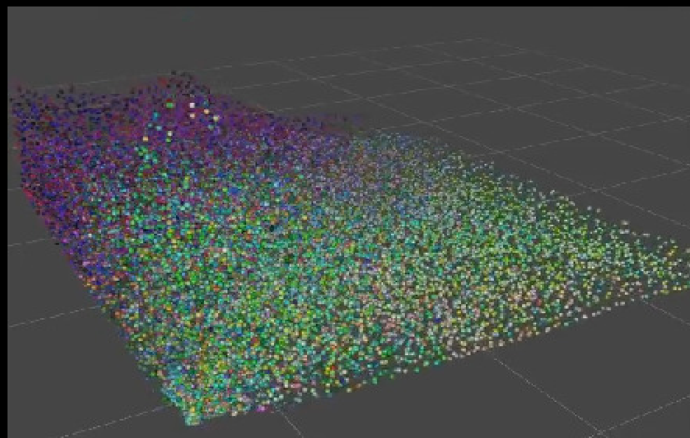
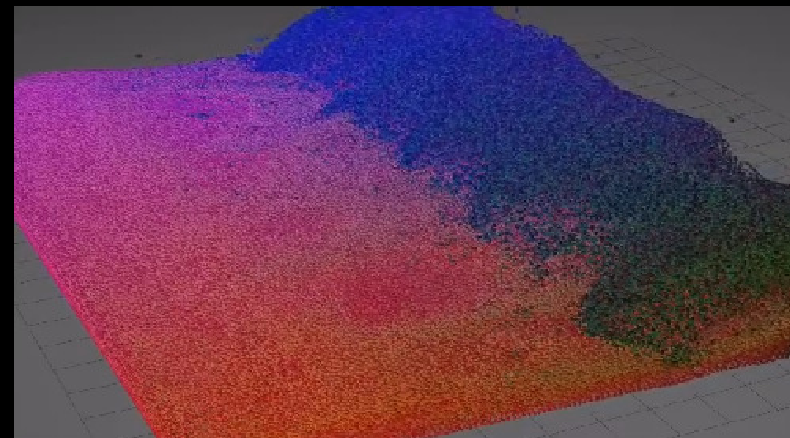
GeForce GTX 460M



Fluids v.2, 2009
16,384 at 32 fps

same hardware
11x faster



Fluids v.3, 2013
193,487 at 32 fps

Thank you!

- Rama C. Hoetzlein, rama@rchoetzlein.com

http://fluids3.com