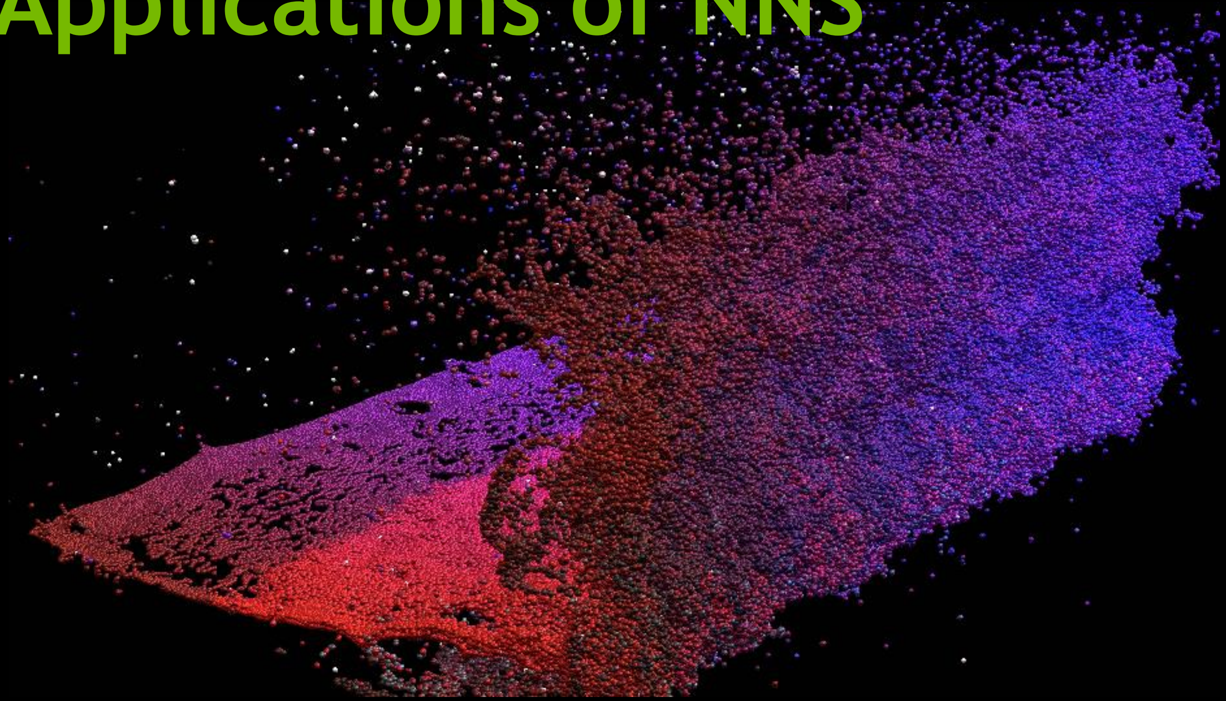
GPU TECHNOLOGY CONFERENCE

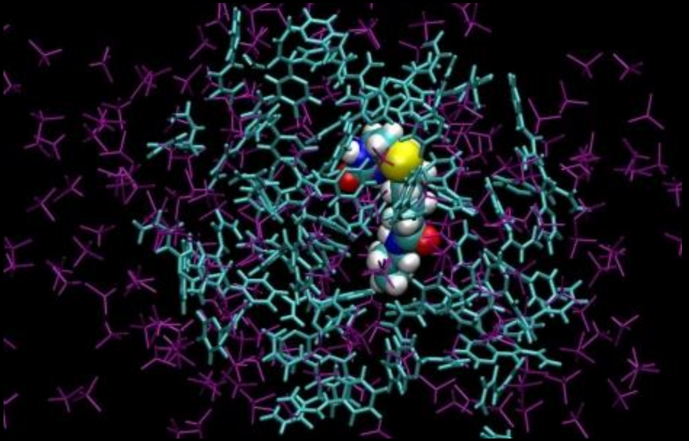
FAST FIXED-RADIUS NEAREST NEIGHBORS: INTERACTIVE MILLION-PARTICLE FLUIDS

Rama C. Hoetzlein, Graphics Devtech, NVIDIA

Applications of NNS



Fluid Simulation

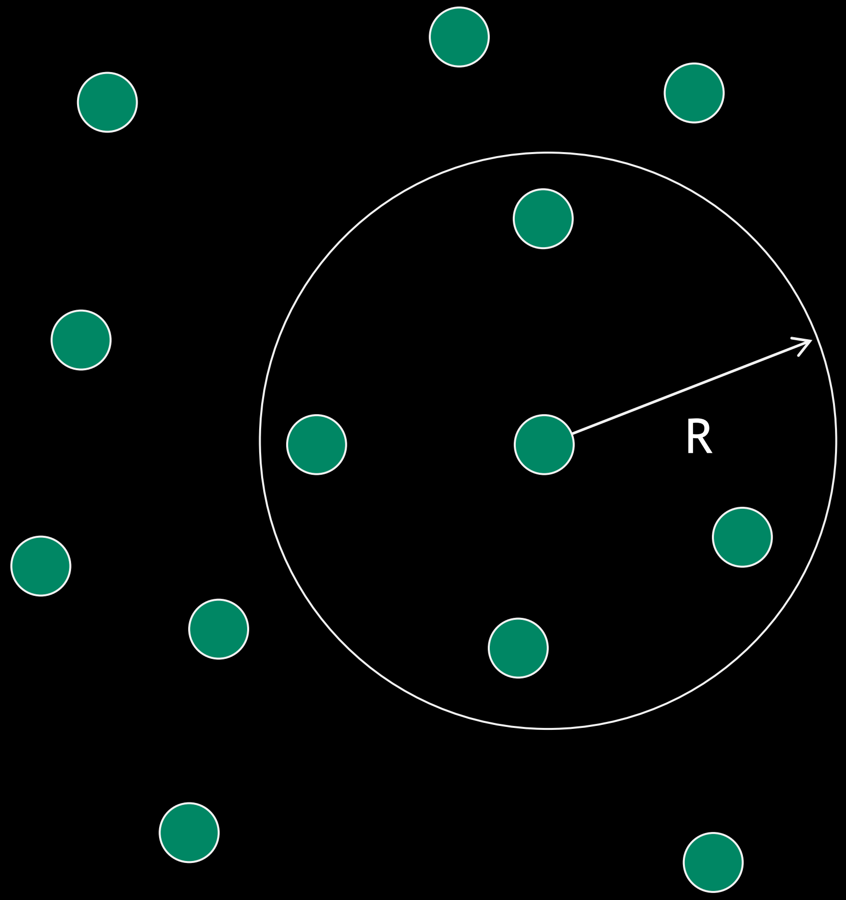


Molecular Modeling

Cognitive Science – Behavioral simulation

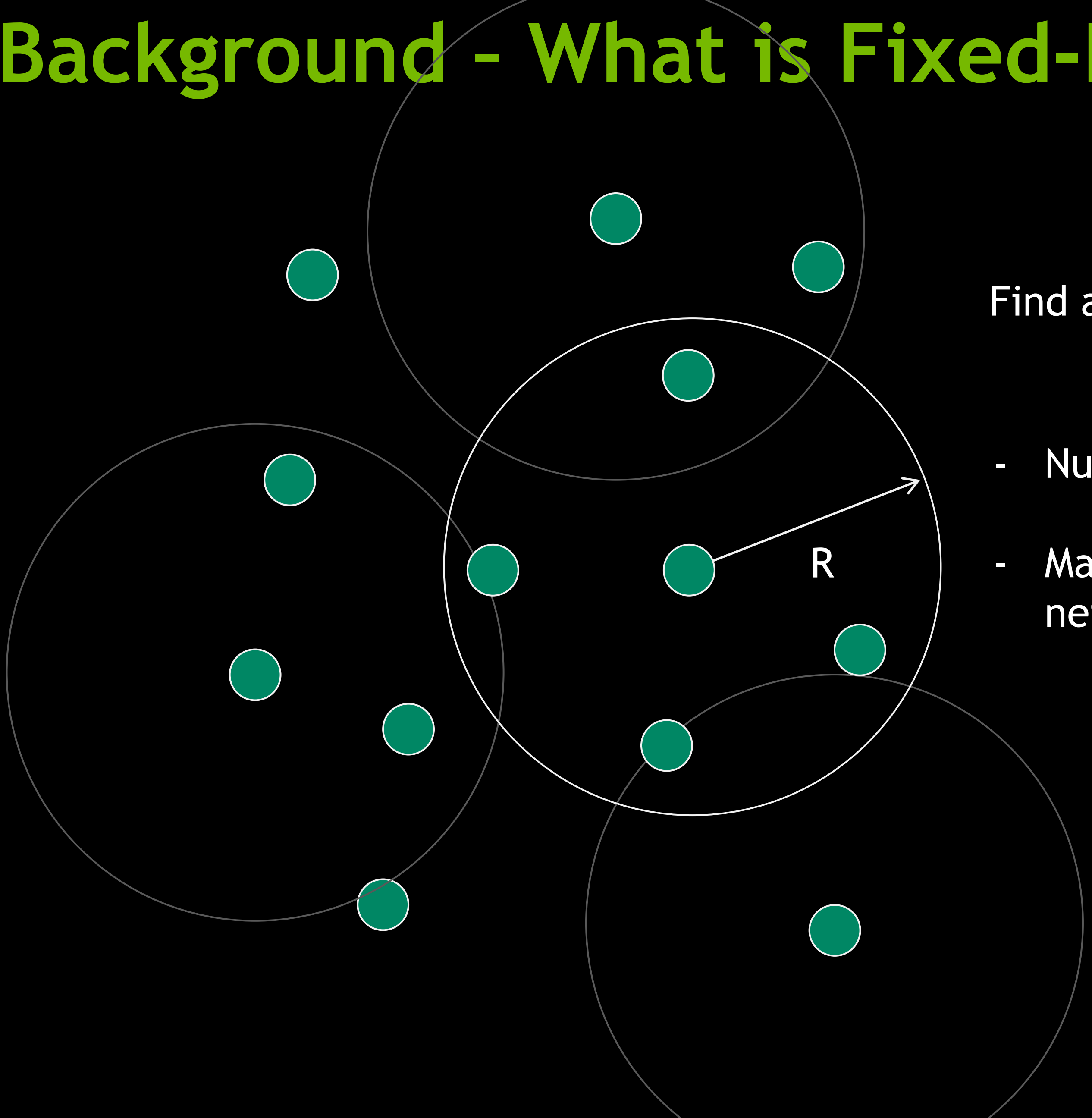
3D Scanning - Point Cloud Reconstruction

Background - What is Fixed-Radius NNS?



Find all neighbors in a fixed radius R

Background - What is Fixed-Radius NNS?

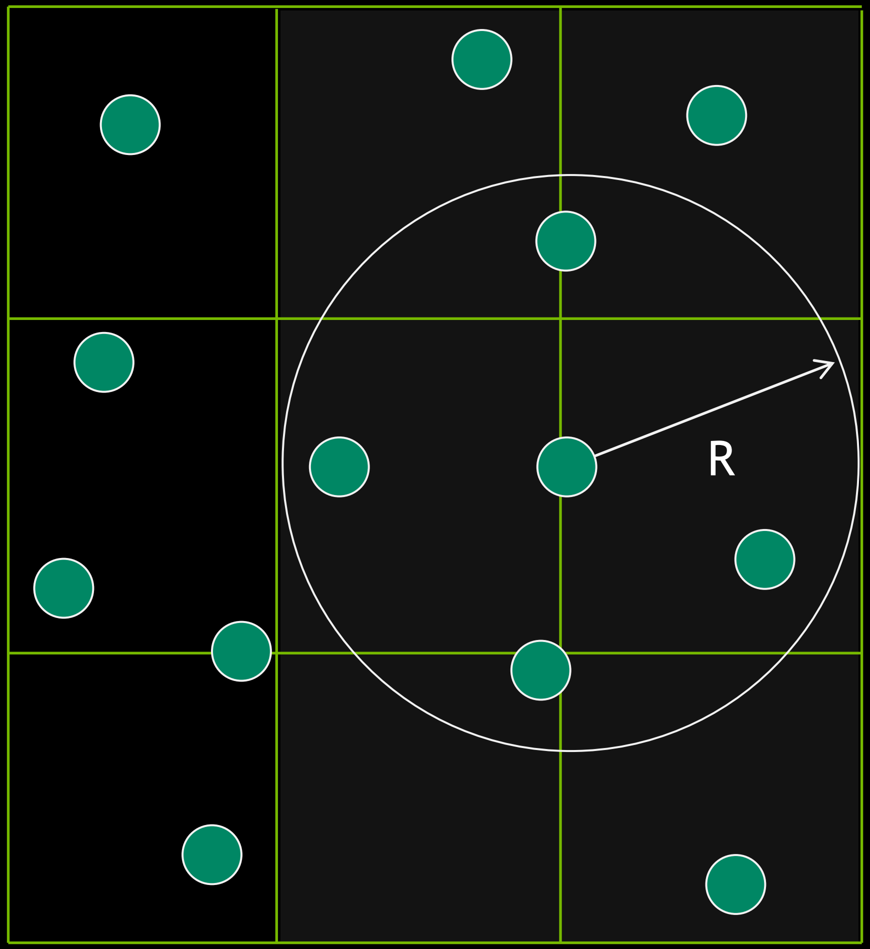


Find all neighbors in a fixed radius R

- 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:

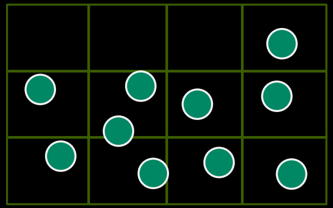
1. Partition space equally into bins

2. Insert each particle into bins

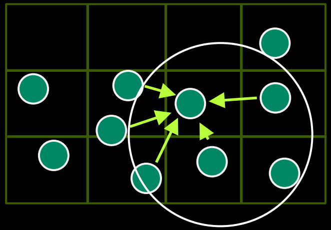
3. Only need to search particles found in neighboring bins

$O(Nk)$

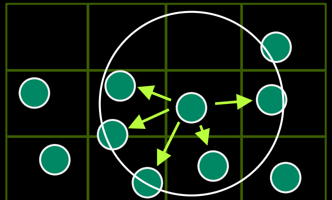
Use in Simulation



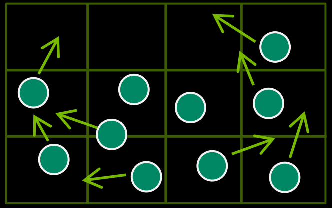
Insert Particles



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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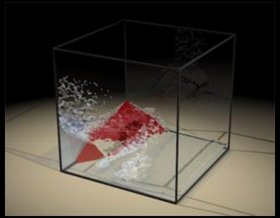
Research Background

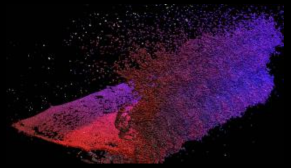
Fluid Simulation

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

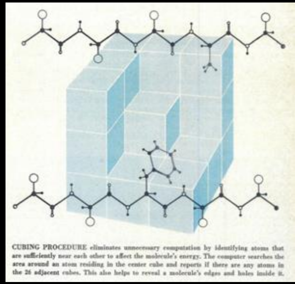


2009 Solenthaler
Predictor-Corrector (PCISPH)

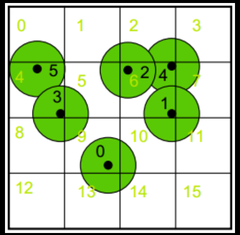
2013 Mathias & Muller
Position Based Fluids



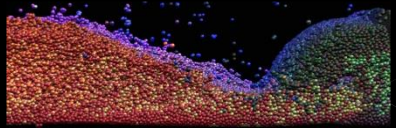
Fluids v.3 (SPH)



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

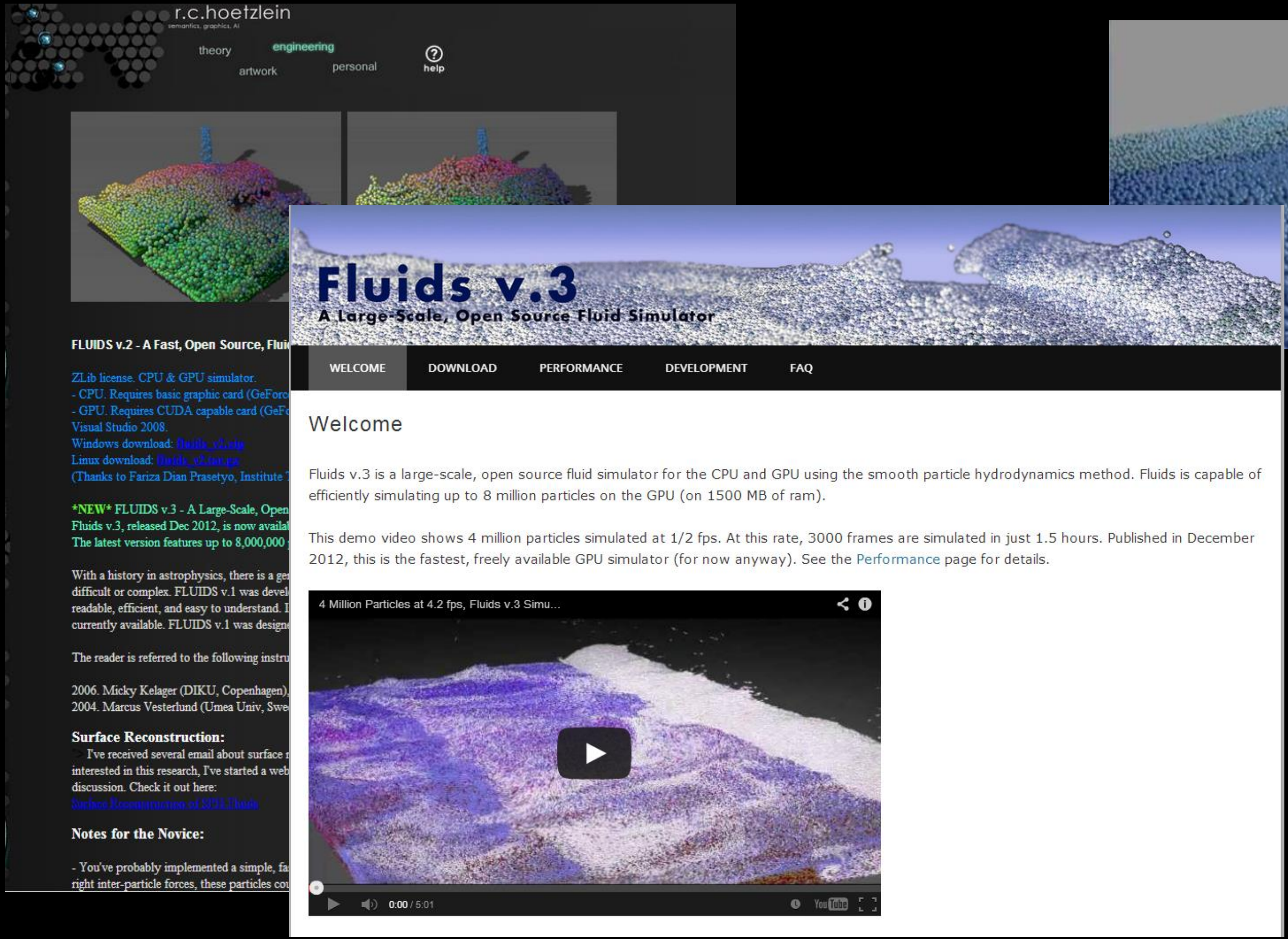


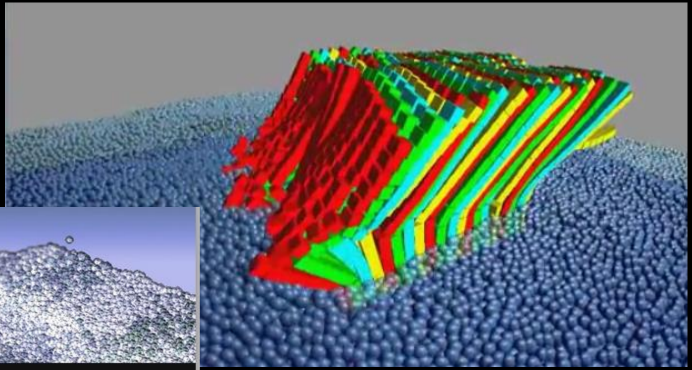
2010 Simon Green
Particle Simulation using CUDA
Parallel Radix Sort



2013 Hoetzlein
Parallel Counting Sort NNS

Nearest Neighbor Search

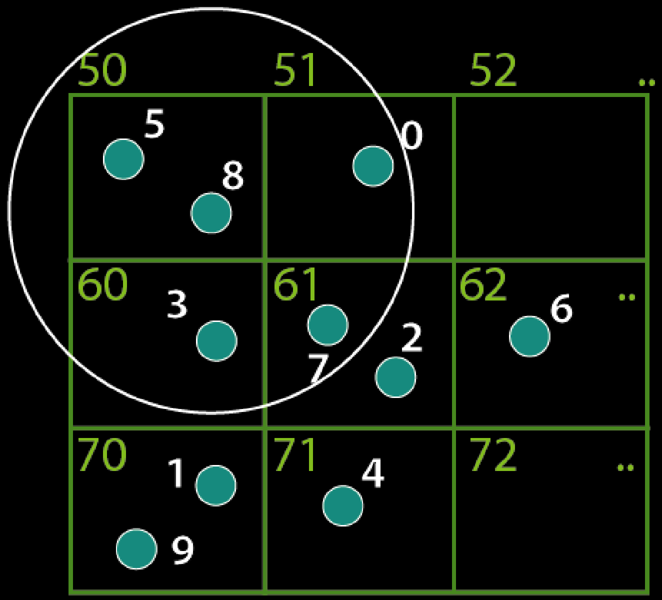




Fluids v.3 http://fluids3.com

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

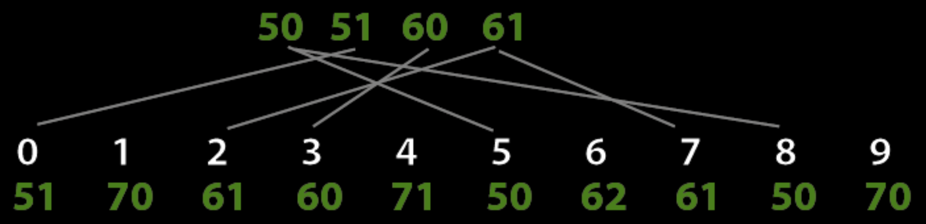
Grid Search



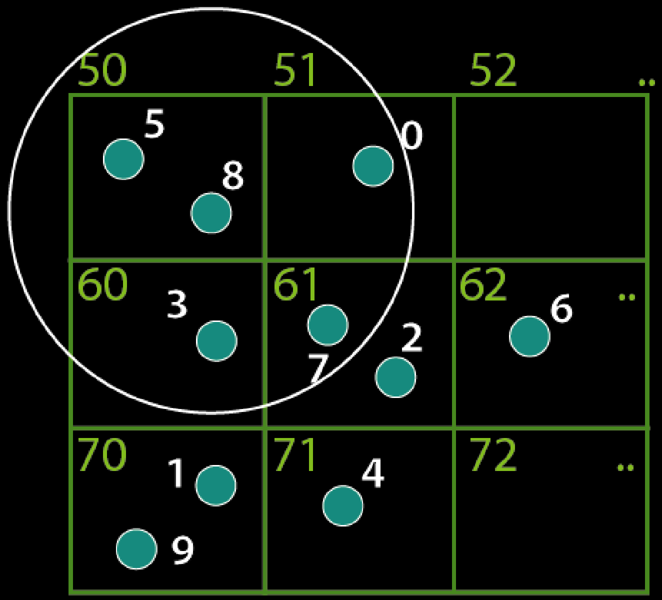
Original Input

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

Neighboring Bins



Grid Search



Goal:
Sort on every frame

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

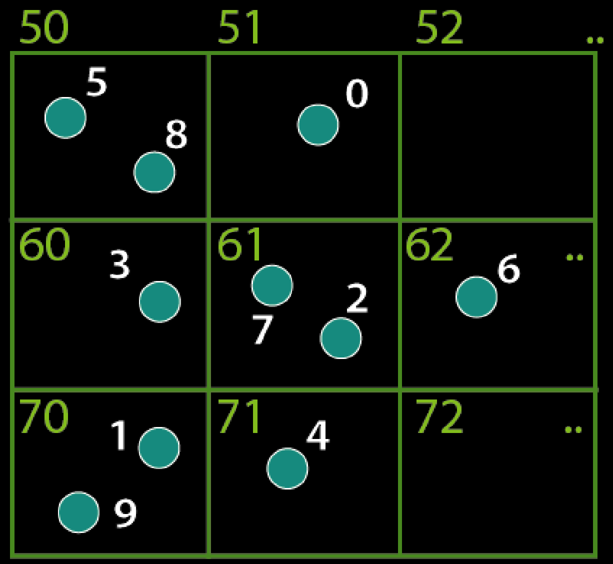
COHERENT READS !

Radix Sort

Previous method (Green 2008)

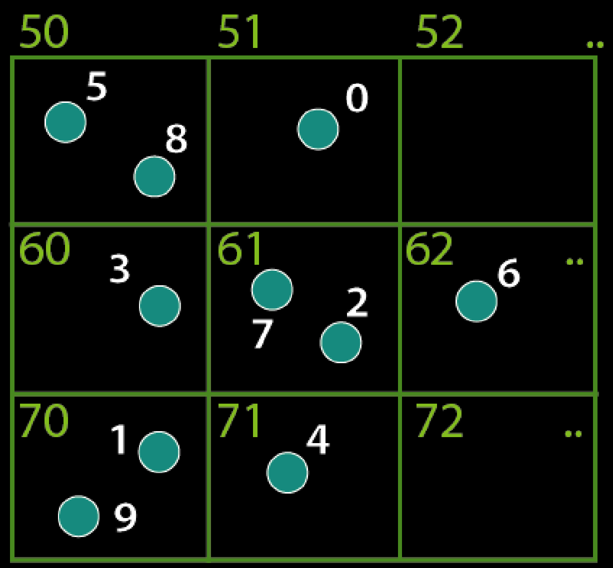
Input

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



Radix Sort

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

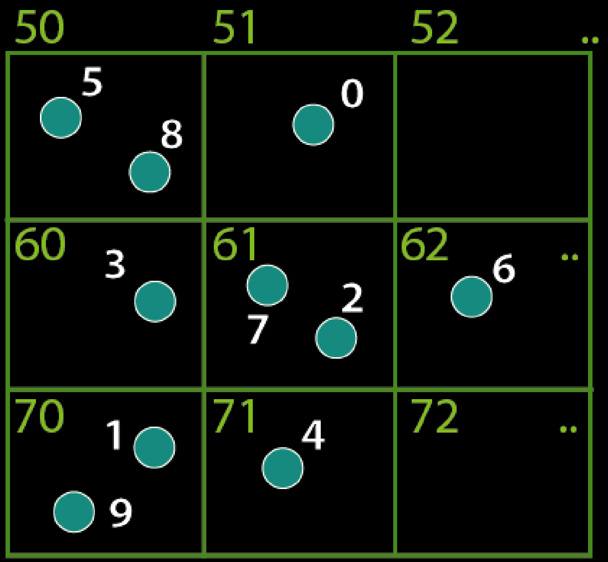
Digit 0

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

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

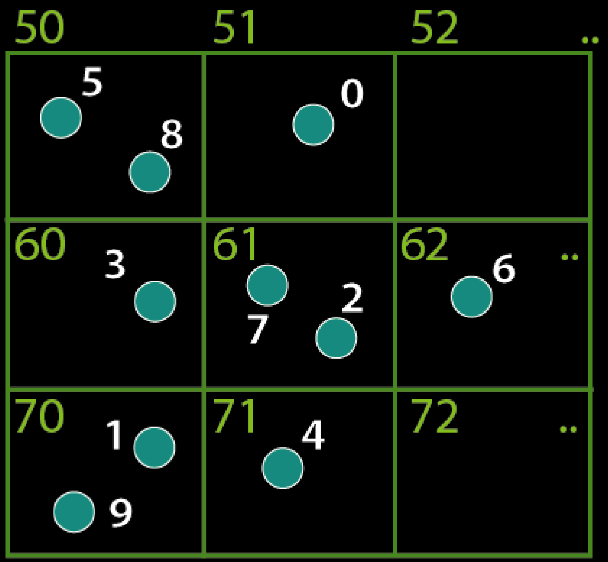
0	1	2	3	4	5	6	7	8	9
51	70	61	60	71	50	62	61	50	70

0 = 5   1 = 4   2 = 1

70	60	50	50	70	51	61	71	61	62

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

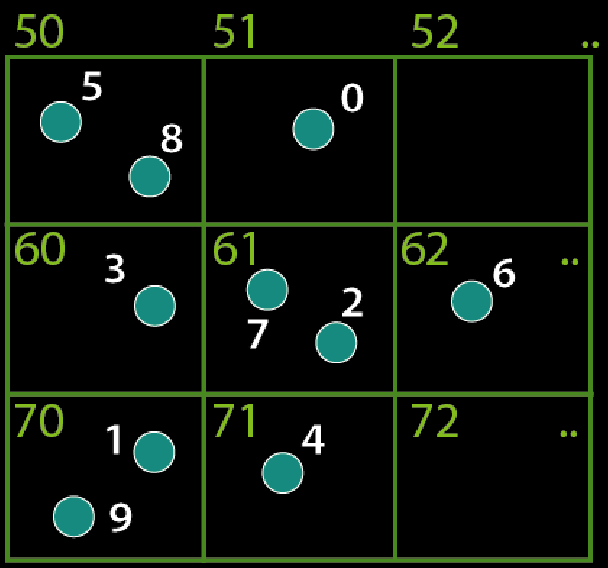
0	1	2	3	4	5	6	7	8	9
70	60	50	50	70	51	61	71	61	62

5 = **3** 6 = **4** 7 = **3**

50	50	51	60	61	61	62	70	70	71

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

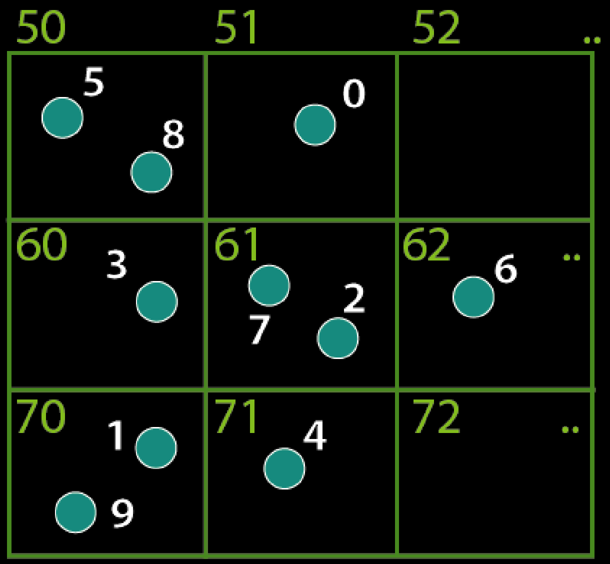
Output

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

Counting Sort

Input

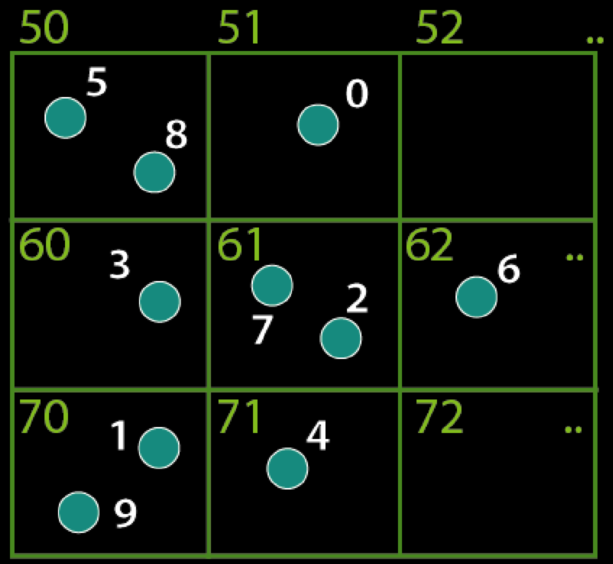
0	1	2	3	4	5	6	7	8	9
51	70	61	60	71	50	62	61	50	70



Observations:

A full sort on key is not necessary.
Inside a bin, all keys will be duplicated.
Order in bin not an issue.

Counting Sort



Input

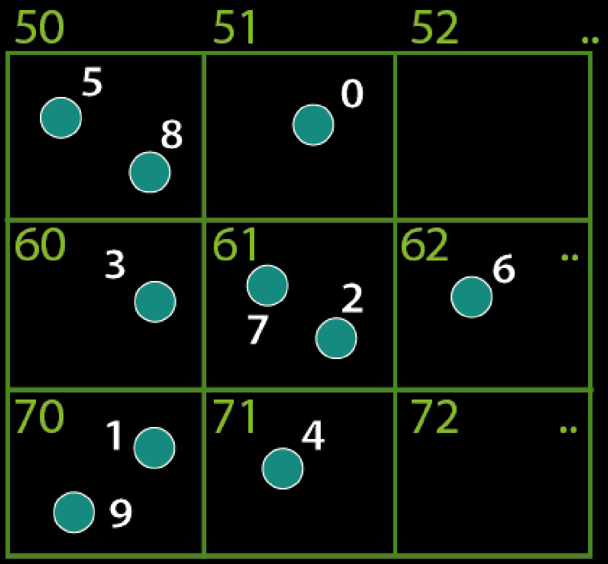
0	1	2	3	4	5	6	7	8	9
51	70	61	60	71	50	62	61	50	70

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

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
51 = 1
52 = 0

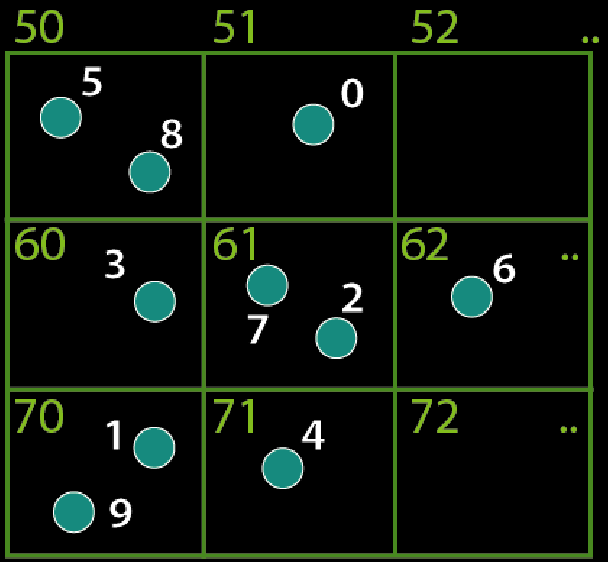
60 = 1
61 = 2
62 = 1

70 = 2
71 = 1
72 = 0

Prefix Sum

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

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

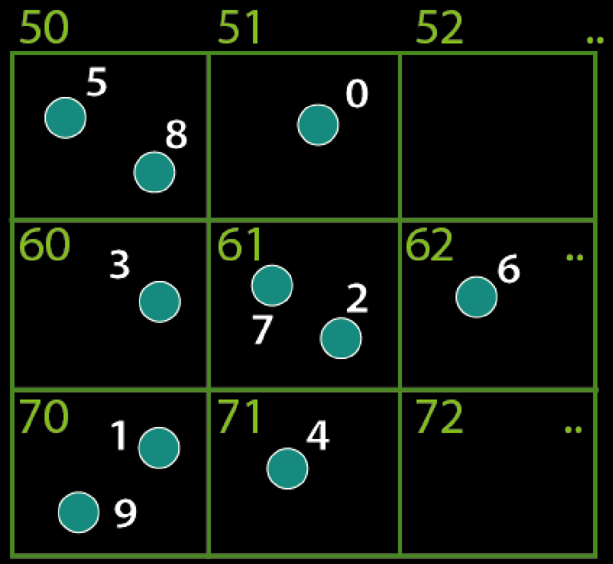
Prefix Sum

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

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

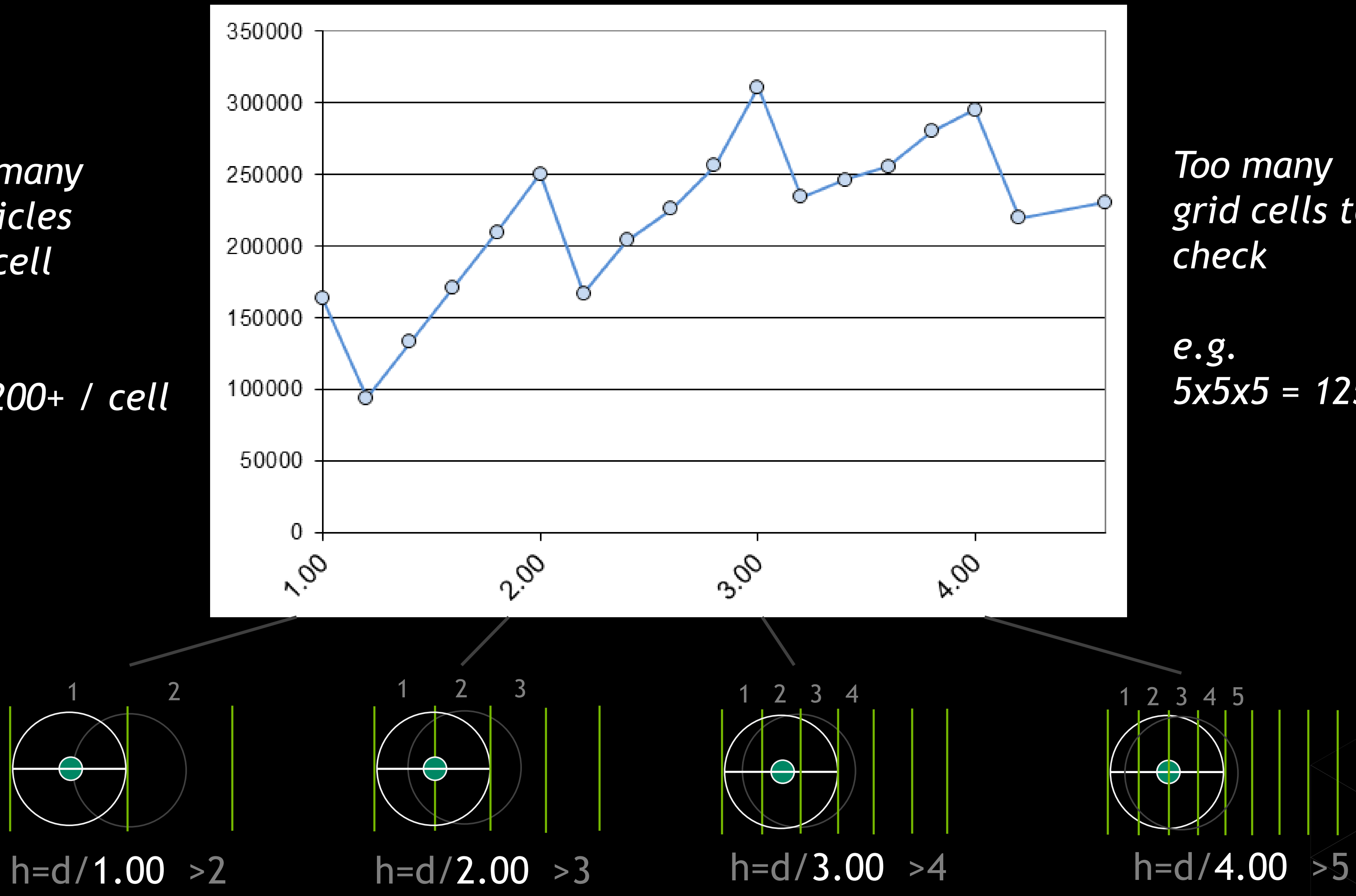
Output

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

Performance Comparison

CUDA Particles (Radix Sort)

calcHashD
- assign particle to cell

sortParticles
- thrust:sort_by_key
- example: CUDA RadixSort
- for 1 to 4 (each byte in key)
  - RadixSum
  - RadixPrefixSum
  - RadixAddOffsetAndShuffle

reorderDataAndFindCellStart
- copy particles in sorted order

collideD

integrateSystem
- thrust::for_each

Fluids v.3 (Counting Sort)

InsertParticles
- assign particle to cell
- AtomicAdd for bin counts & particle indices

CountingSort
- PrefixSumInit, compute bin offsets

CountingSortIndex
- copy particles in sorted order

Collisions

Advance
- integrate system

Performance Comparison

GPU TECHNOLOGY CONFERENCE

CUDA Particles (Radix Sort)

1 calcHashD
  assign particle to cell

sortParticles
  thrust:sort_by_key
  example: CUDA RadixSort
  for 1 to 4 (each byte in key)
4   RadixSum
4   RadixPrefixSum
4   RadixAddOffsetAndShuffle

1 reorderDataAndFindCellStart
  copy particles in sorted order

1 collideD

1 integrateSystem
  thrust::for_each

16 Kernel calls / Frame

Fluids v.3 (Counting Sort)

1 InsertParticles
  assign particle to cell
  → **AtomicAdd for bin counts & particle indices**

CountingSort
1 PrefixSumInit, compute bin offsets

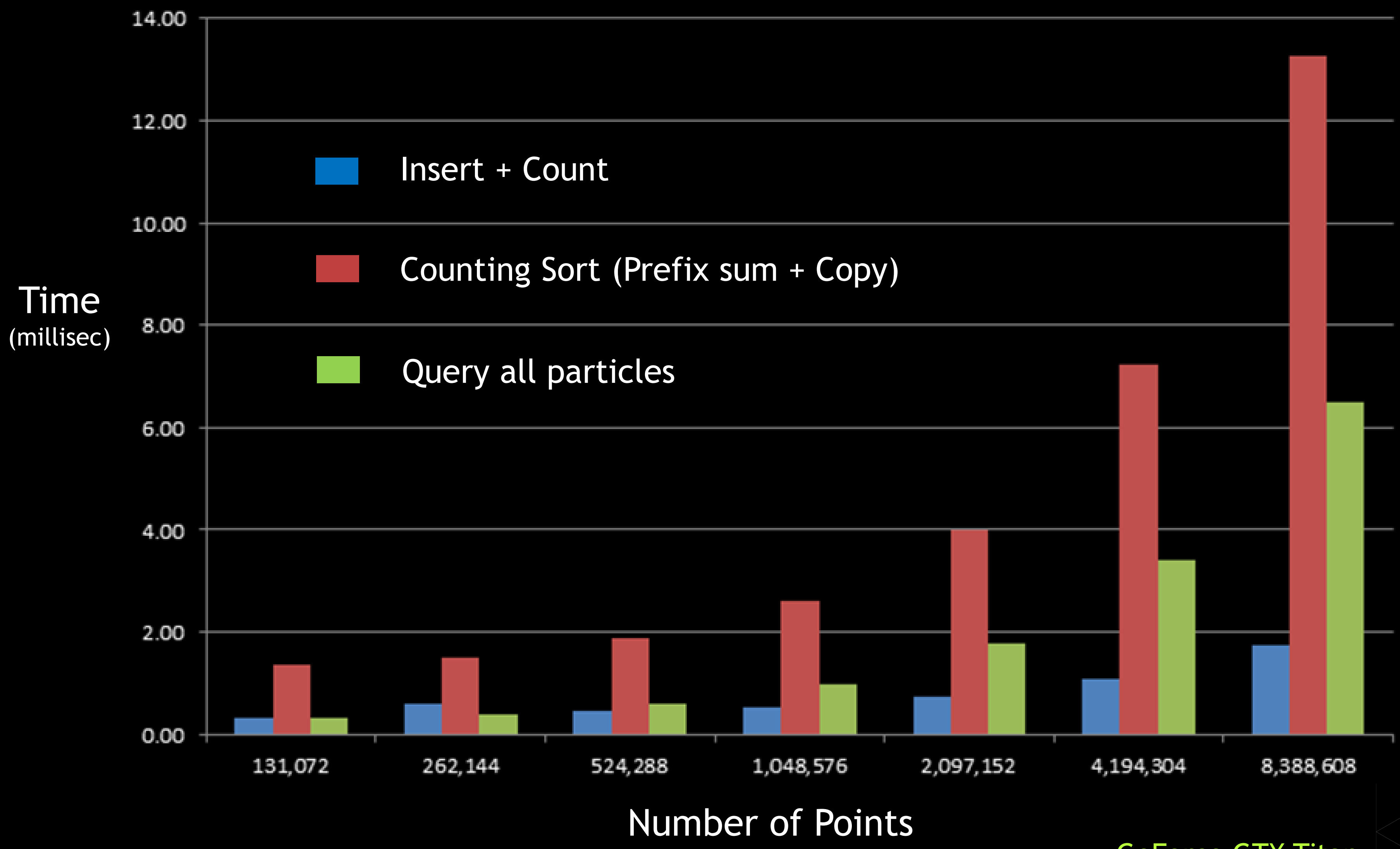
CountingSortIndex
1 copy particles in sorted order

1 Collisions

Advance
1 integrate system

5 Kernel calls / Frame

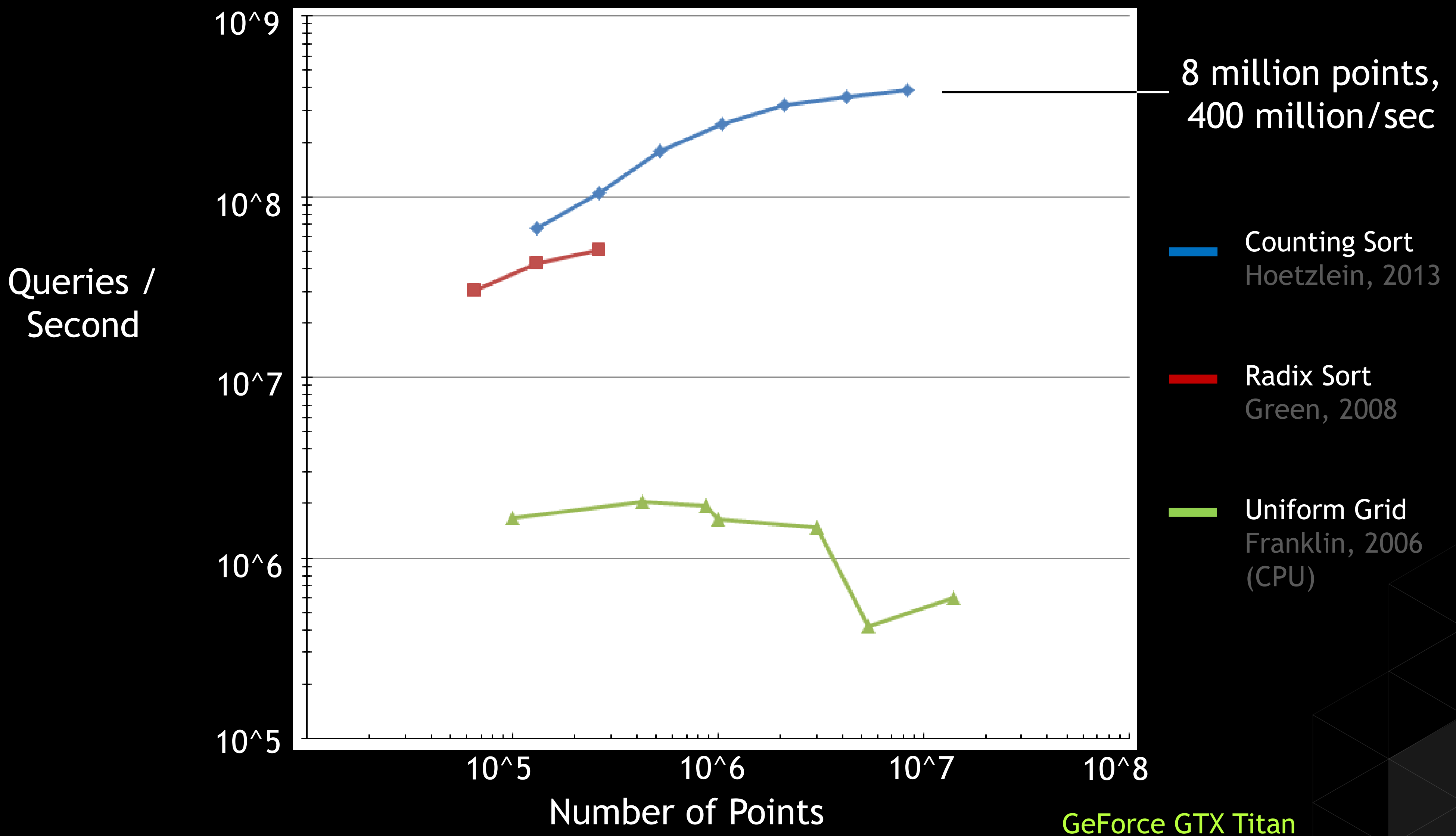
Results (NNS)



GeForce GTX Titan

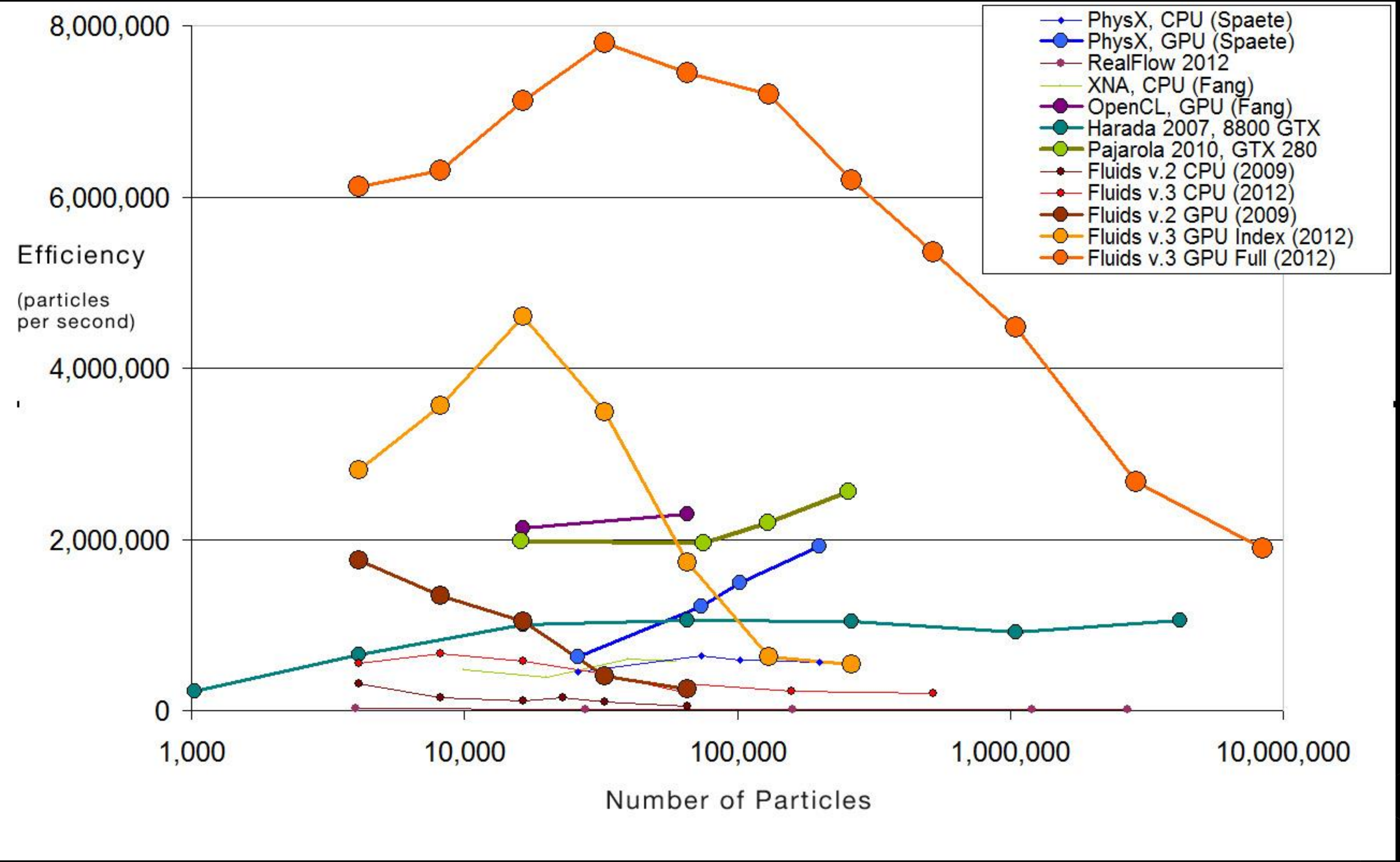
GPU TECHNOLOGY CONFERENCE

Results (NNS)

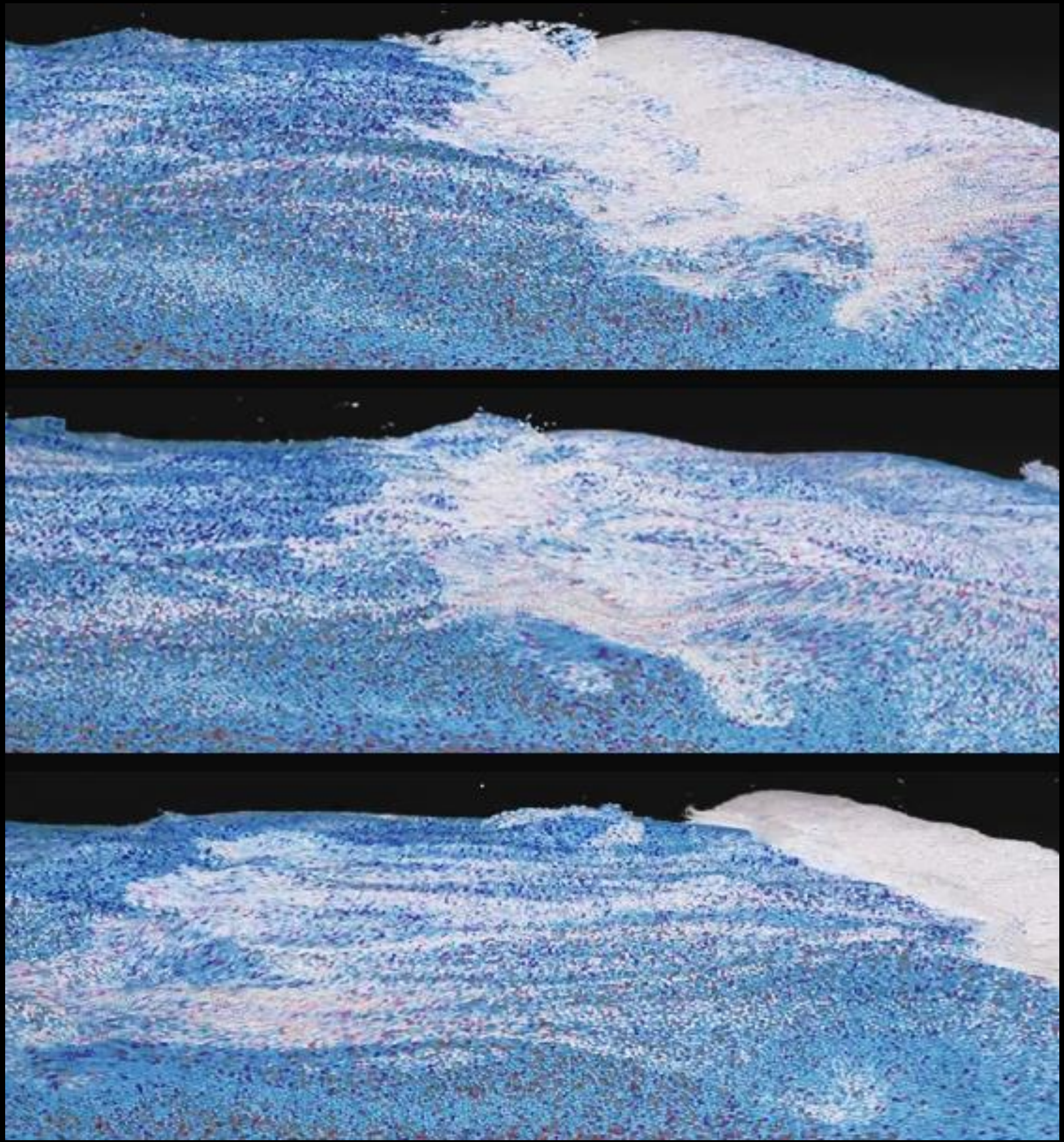


GeForce GTX Titan

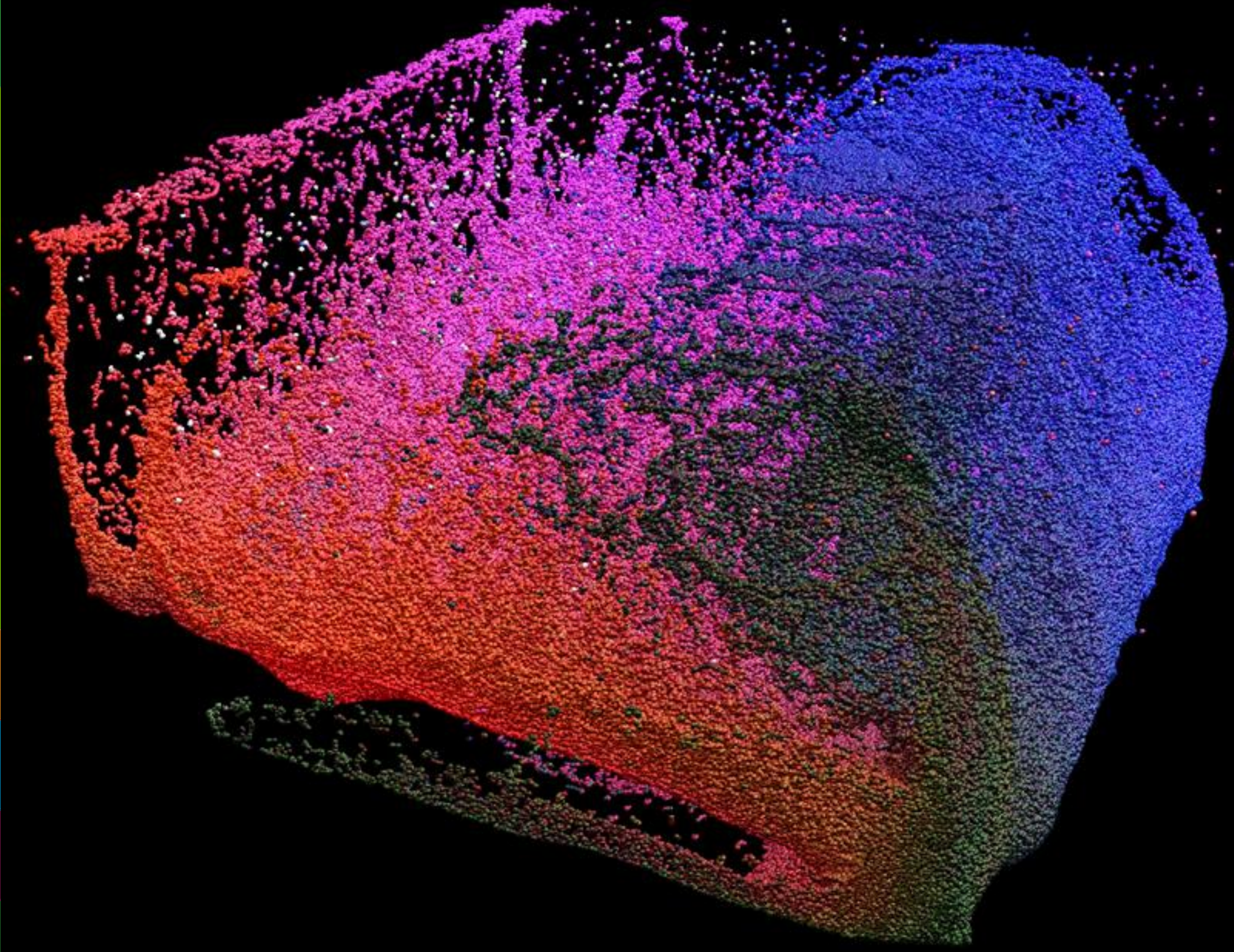
Results (Fluids)

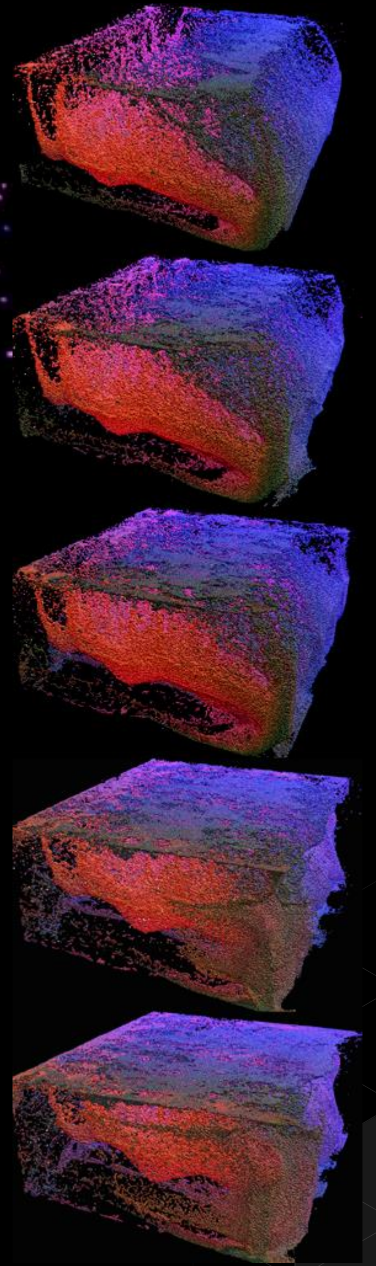


* *Results do not show fluid accuracy or time step.*



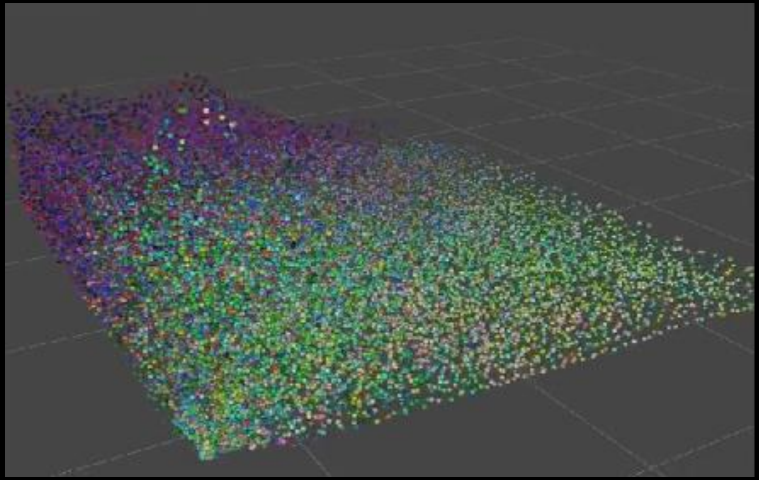
Continuous Ocean Simulation, 4.2 fps, 4,194,304 particles





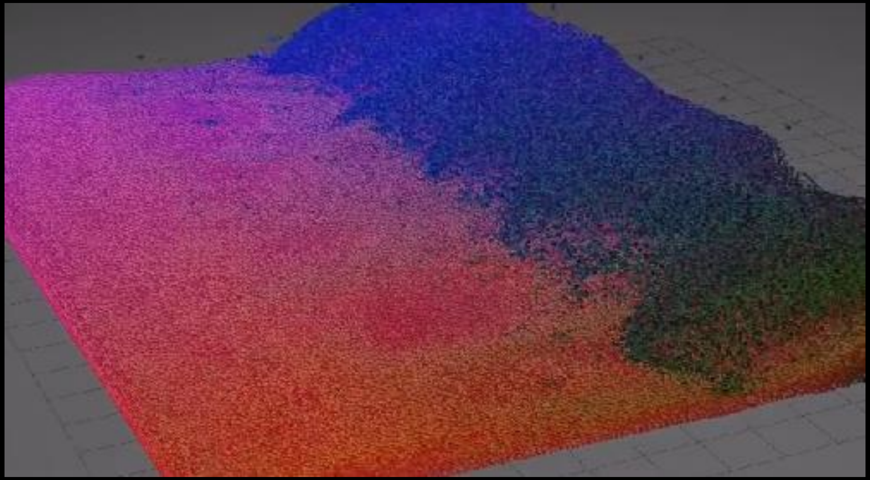
Interactive Microgravity Simulation. 12 fps, 2,097,152 particles

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

http://ramakarl.com/fluids3