GPU Acceleration for Causal Set Quantum Gravity

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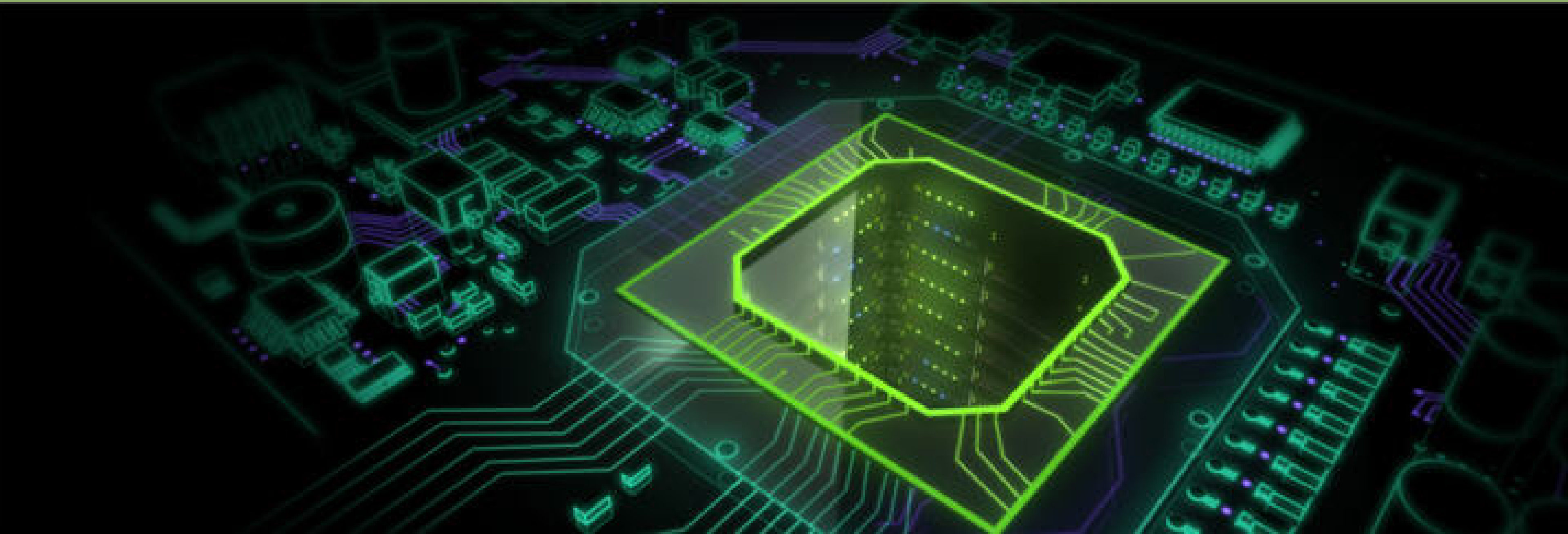
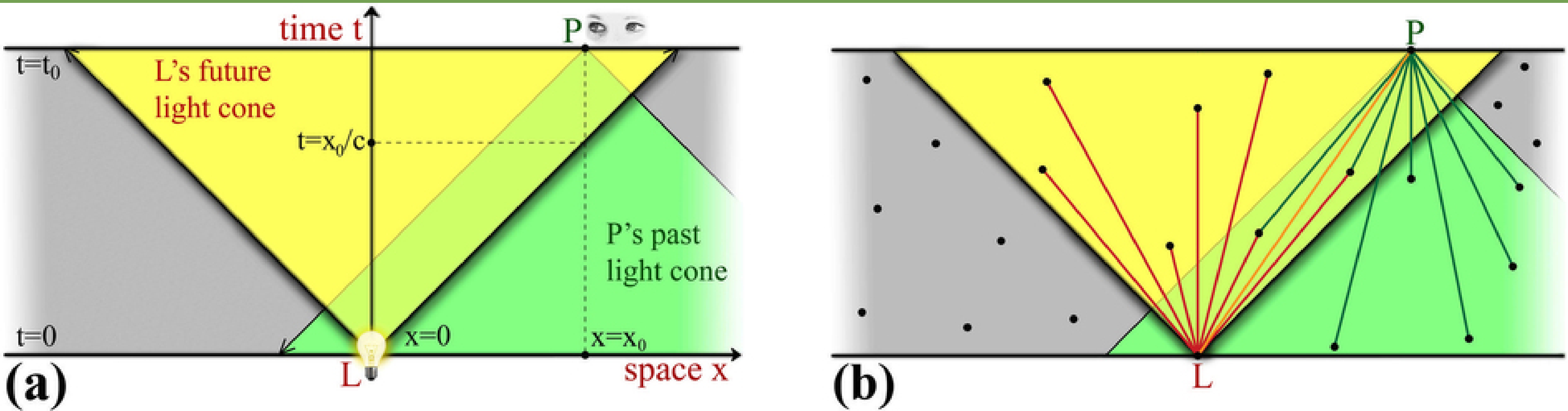


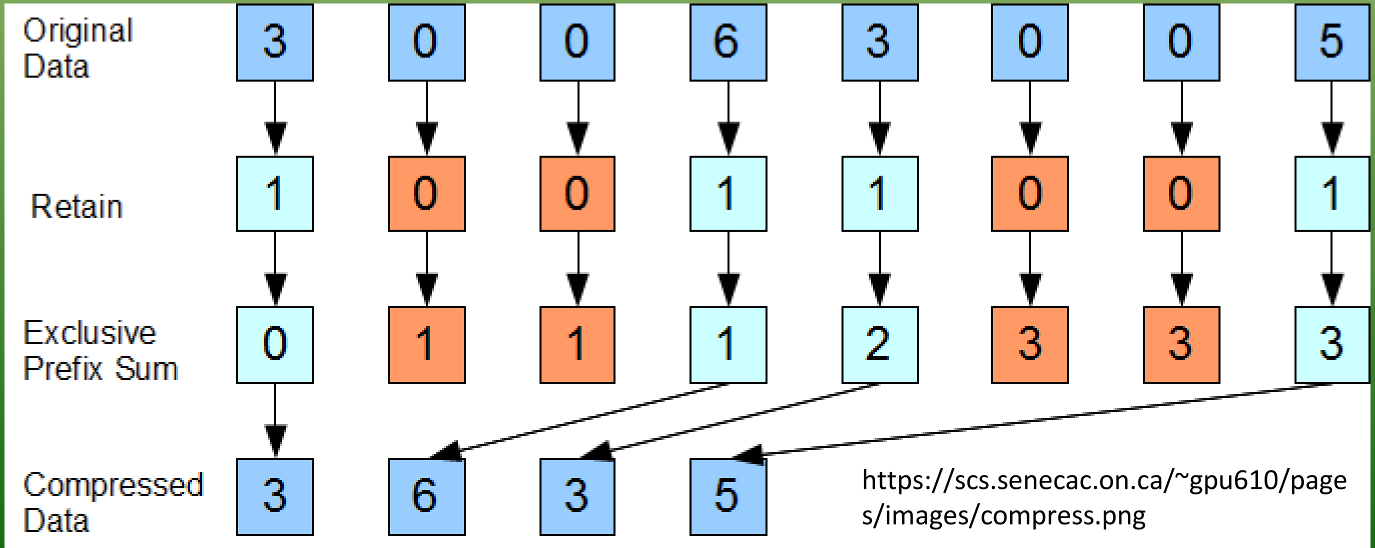
Motivation

- 4-D Network of Spacetime Points (t, θ, ϕ, χ)
- Finding Links is O(N^2) Complexity
- Conformal Time: $\eta(t) = \frac{2a}{3\alpha}\int_0^{at} \sinh^{-2/3}\left(\frac{3t'}{2a}\right) dt'$
- Hyperbolic Law of Cosines: *dx* = $f(\theta_1, \varphi_1, \chi_1, \theta_2, \varphi_2, \chi_2)$
- Causal Connection: $dx < d\eta$



Attempt 1

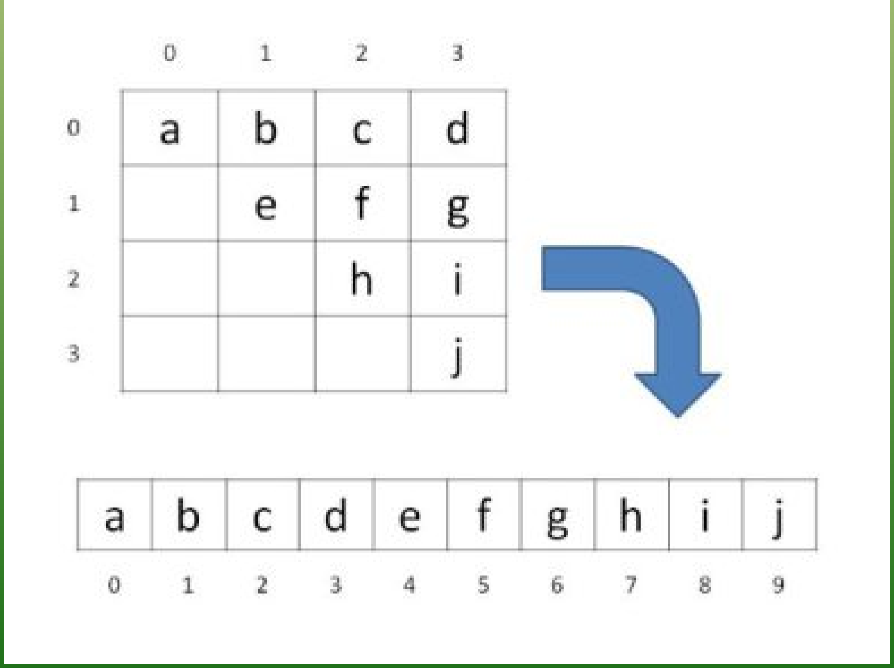
- Each thread compares a pair of points
- Shared Memory:
  - Prefix Sum, Reduction, Compression
- Atomic Add to Global Index
- Write to Global Memory



https://scs.senecac.on.ca/~gpu610/pages/images/compress.png

Attempt 2

- Shared memory is not always a good choice
- Atomic operations good if sparse
- Finding the (*i,j*) from *tid* is O(*N*) in complexity



http://jamesmccaffrey.files.wordpress.com/2010/05/matrixtoarray.jpg?w=391&h=325

Attempt 3

- Triangular Elements Mapped
  - Now the operation is O(1) complexity
- Maximize Instruction Throughput

1. 2048 Threads per Multiprocessor
2. 64 Warps per Multiprocessor
3. 16 Thread Blocks per Multiprocessor
4. 1024 Threads Per Thread Block

Was using 32 x 32 x 1 to maximize #4

Now using 128 x 1 x 1 to maximize #1-3

Attempt 4

- Shared memory re-introduced
  - One node shared among a block now
- Each thread handles 2 pairs
  - Total of ${N^2}/{4}$ threads executed in the kernel
  - Atomic addition handled in pairs (rare to get a pair)

Attempt 5 (Final)

- Texture/Surface Memory
  - Not appropriate for this task (slower by 2%)
  - Better for nearest neighbor problems
- Mapped Pinned Memory (Zero-Copy)
  - Negligible increase in speed
  - Good for single read/write to global
- Bitonic Sort of Edge List
  - Very fast: O($\log^2 N$) in complexity
- **Result: 17.23 s on GPU vs 304.25 s on CPU for 51,200 spacetime nodes**

Next Steps

- Generating Random Numbers
  - CURAND Package
- Traversing the Network
  - Given an entrance and an exit, what percent of random walks succeed?
  - Test every combination of entrances/exits
  - As a function of the dark energy

Questions?