Game Physics on the GPU with PhysX 3.4

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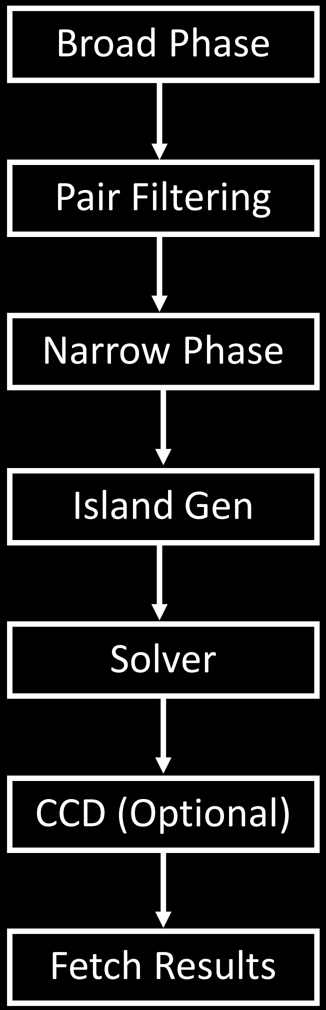
PhysX 3.4 Features

- GPU Rigid Bodies
- Improved threading and performance
- New CCD mode
- Low-level immediate mode
- Enhanced Determinism
- Faster, more robust convex hull cooking
- Faster mid-phase structure
- Serializable scene query trees for level streaming
- Split-sim
- Improved vehicles

Basic PhysX Rigid Body Pipeline



Pipeline Stages

- Broad Phase
  - Produces set of candidate pairs that are potentially interacting
  - Quickly rejects non-overlapping pairs
  - Uses approximate bounds (e.g. AABBs or spheres)
- Pair Filtering
  - Apply application-rules to permit/disallow pairs to be processed by narrow phase or solver
- Narrow Phase/Contact gen
  - Processes the set of pairs produced by broad phase
  - Determines if the geometries are actually interacting, in which case generates contacts.

Main Pipeline stages cont.

- Island Management
  - Groups bodies into islands
  - Island = collection of bodies interacting via contacts or constraints
  - A given object can be a member of only 1 island unless that body is static or kinematic
- Constraint Solver
  - Solves islands
  - Produces constraints from the set of contacts and joints
  - Computes new velocities and transform for rigid bodies that satisfy constraints.
- Fetch Results
  - Buffering
  - Fire user callbacks
  - Update Scene Query structures

GPU vs CPU

- GPU
  - Massive FLOPS and memory bandwidth.
  - 1000s of compute cores
  - Lower clock frequencies
  - Longer-latency instruction pipeline
  - Highly-sensitive to memory access patterns and branching
  - Algorithms must scale to 1000s of threads.

- CPU
  - Lower FLOPS and memory bandwidth
  - Small number of cores
  - Higher clock frequencies
  - Lower-latency instruction pipeline
  - Tolerant to memory access patterns branching
  - Executes sequential and parallel algorithms well

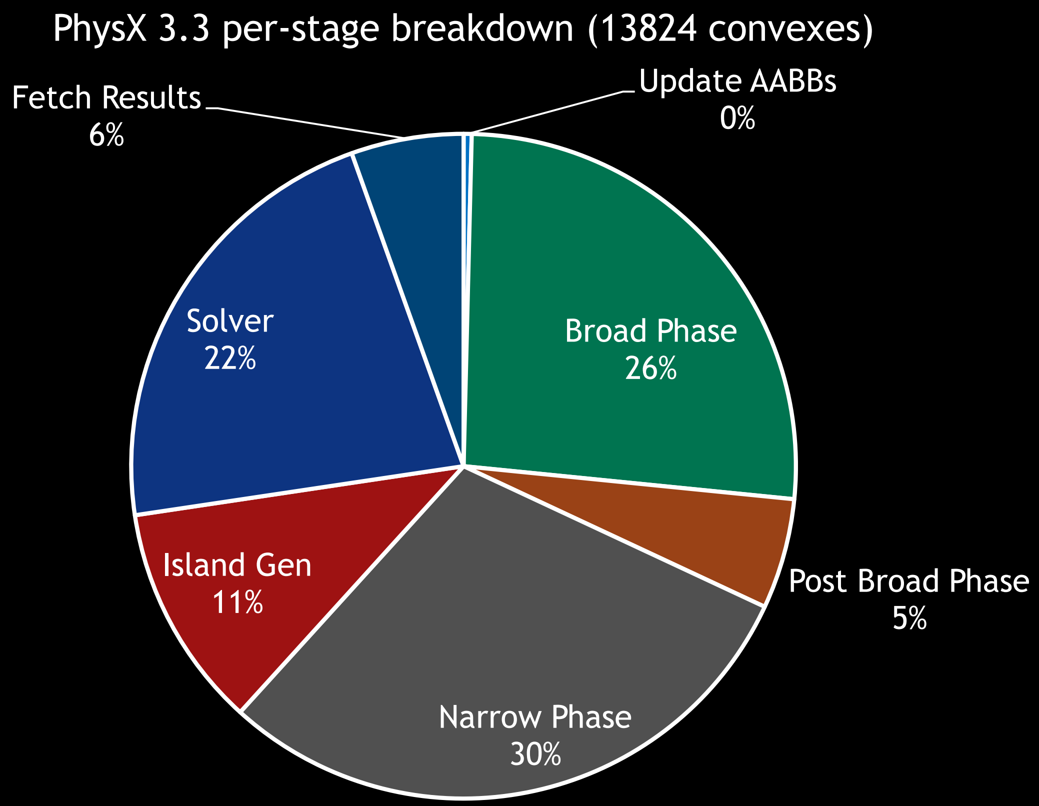
GPU Rigid Body Goals

- Easy to integrate
- Same semantics and behavior as CPU PhysX
- Support full PhysX feature-set
- Must be fast!
- Minimize latency to access results
- Gameplay-effecting simulation
- Plan:
  - Port broad phase, narrow phase and solver to GPU
  - Leave rest of pipeline on CPU

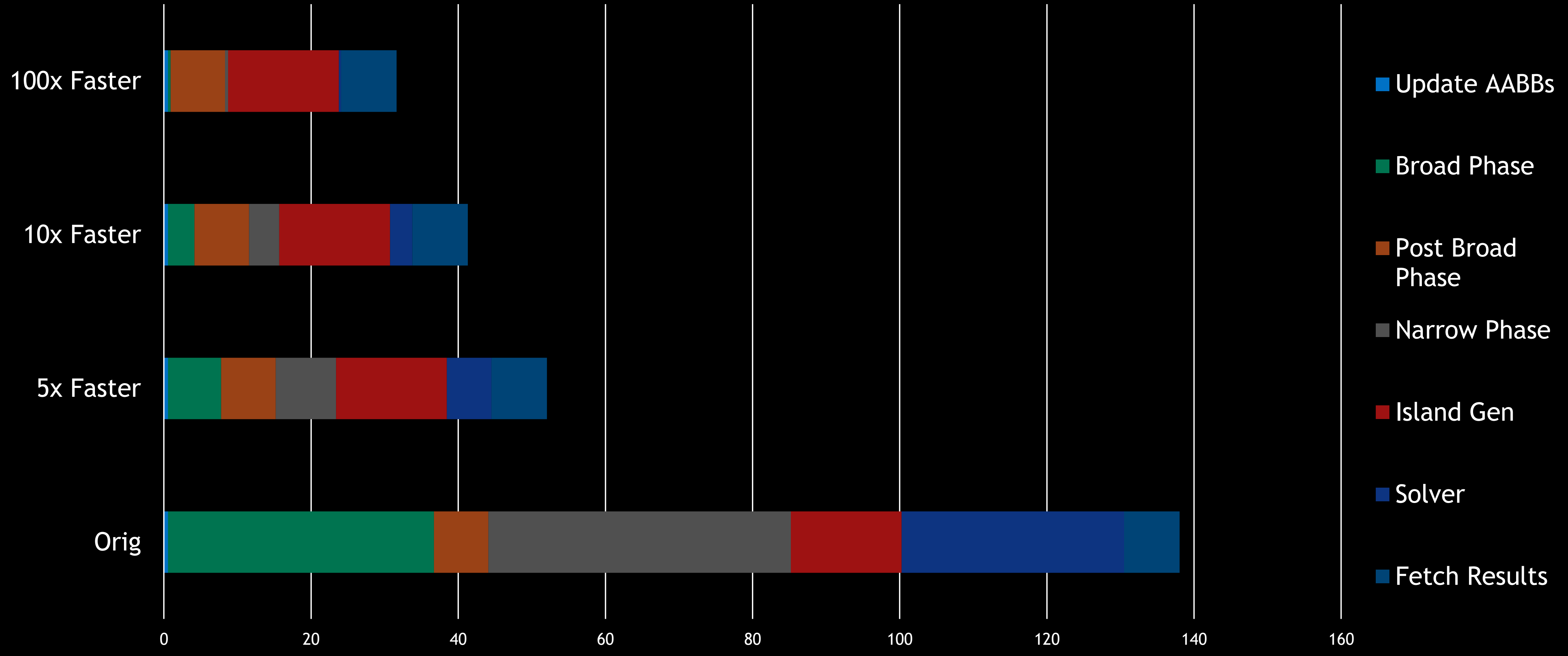
Potential performance gains?

- Moving pipeline stages from CPU to GPU can yield significant performance gains
- It can also introduce additional overhead
  - Memory transfer
  - Kernel dispatch overhead
- Amdahl's Law applies
  - The serial stages of the pipeline will become a bottleneck as the number of cores processing the parallel stages increases

A PhysX 3.3 CPU simulation frame



What if GPU stages were faster?



Performance in PhysX 3.3

- Broad Phase, narrow phase and solver ~70-80% of total simulation time
  - Meaning maximum speed-up is limited to 3.3-5x
- Not enough!
- Serial stages of pipeline quickly become bottleneck!
- Either migrate more to GPU or optimize CPU code

An Improved Physics Pipeline!

- PhysX 3.3 pipeline too serial
- New pipeline parallelizes more stages
- Optimized parallel interaction framework to scale to 1m+ pairs
- New incremental island management
- New sim controller and AABB manager
  - Shares common information between broad phase, narrow phase and scene query to avoid redundant work
- Optimized CPU contact generation and constraint solver

An Improved Physics Pipeline!

- Improved memory footprint and cache coherence
- Decouple and overlap pipeline stages so CPU and GPU can both be busy at the same time
  - Also provides better multi-core CPU performance
- New split fetchResults API to enable application to parallelize callbacks
  - Callbacks can potentially become a bottleneck!
- New split sim API

GPU Rigid Bodies in PhysX 3.4

- Hybrid CPU/GPU rigid body simulation
- Execute the following Rigid Body pipeline stages on GPU
  - Broad Phase, Narrow Phase, Solver
  - Miscellaneous state management, bounds computation etc.
- Execute the following stages on the CPU
  - Island Management
  - Shape filtering and interaction management
  - CCD
  - Triggers
  - User callbacks
  - Updating scene query structures

GPU Broad Phase

- Two-phase incremental broad phase algorithm
- Produces only delta pairs
  - New or lost pairs since last time BP was run
  - Significantly reduces data transfer between CPU and GPU
- Highly-scalable
- Often orders of magnitude faster than commonly-used CPU sweep and prune approaches.
- Can be enabled without enabling the rest of the GPU pipeline
- PxAggregates are partially handled on CPU
  - PxAggregate is usually not beneficial if using GPU broad phase

GPU Narrow Phase

- PCM-based
  - Supports boxes, convex hulls, meshes and heightfields
  - Convex hulls must have <= 64 verts and <= 32 verts per-face
  - Meshes and convex hulls need extra cooked data
- CPU processes
  - Incompatible shape pairs (sphere, capsule, plane, complex convex)
  - Pairs with contact modification enabled
- Contacts generated on CPU are automatically transferred to GPU to be processed by the solver
- Contacts generated on GPU are automatically transferred back to CPU as needed
- Trigger pairs are processed on CPU
  - Trigger behaviour can be emulated on GPU using touch found/lost events

GPU Constraint Solver

- Hybrid PGS/MS constraint solver
- Provides equivalent behaviour to PhysX CPU solver
- Extracts and exploits massive levels of parallelism from within islands
- Utilizes an efficient lazy algorithm to determine dependency chains
  - Cost is proportional to how much connectivity changes rather than the complexity of the graph itself
- Solves all contacts and joint constraints
  - Native support for D6 joints (full pipeline executed on GPU)
  - Other joint types have joint shaders execute on CPU and results transferred to GPU for processing

GPU Constraint Solver continued

- Supports most features supported by CPU
  - Force reports and force thresholding
  - Breakable joints
  - Applies all modifiable properties
    - Limiting contact/constraint force, target velocity, max de-penetration velocity, dominance and local mass modifications
- Doesn’t currently support articulations
- Designed to provide good performance while using as few GPU compute resources as possible.

GPU Simulation Controller

- Body and shape state management
- Manages pair and constraint states
- Controls actor sleeping
- Handles user state modifications to actors and pairs
  - Efficiently keeps CPU and GPU view of current body/shape/pair states up-to-date by lazily updating states as required
- Buffers external/internal states to minimize per-frame data transfers between CPU and GPU.

Ease of Integration

Basic scene initialization

```
PxSceneDesc sceneDesc(gPhysics->getTolerancesScale());

sceneDesc.gravity = PxVec3(0.0f, -9.81f, 0.0f);

sceneDesc.cpuDispatcher= PxDefaultCpuDispatcherCreate(4);

sceneDesc.filterShader= PxDefaultSimulationFilterShader;

gScene = gPhysics->createScene(sceneDesc);
```

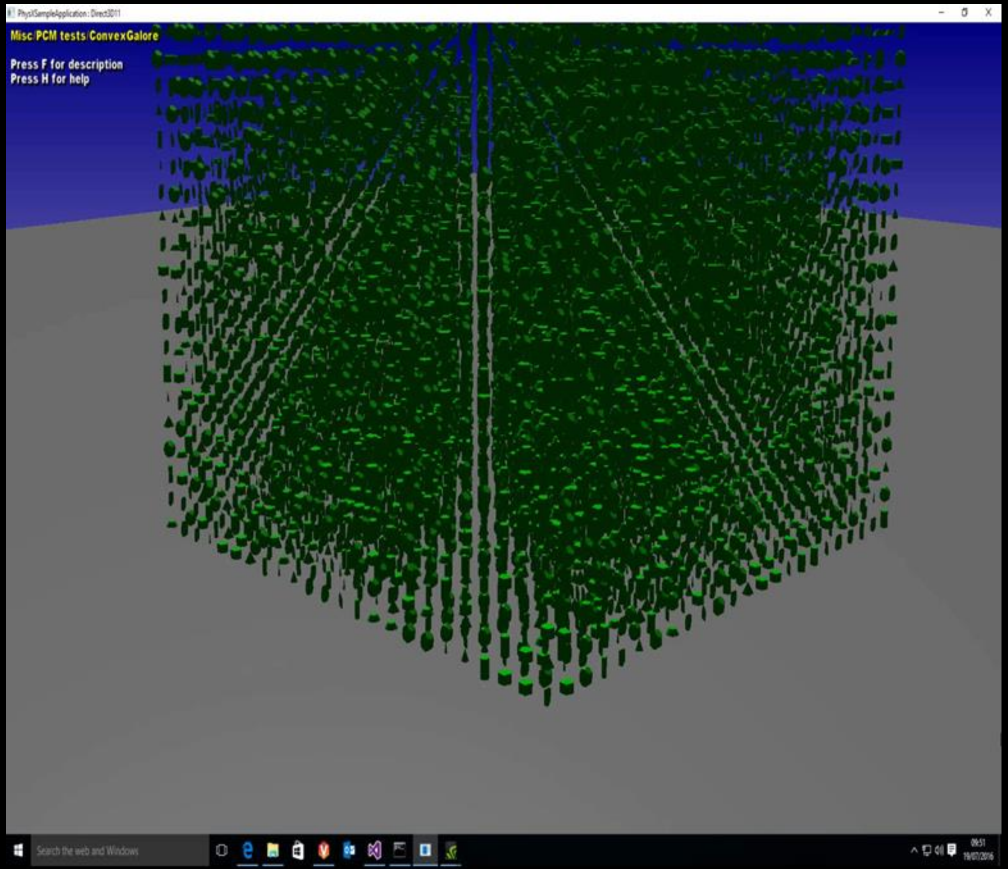
Basic scene initialization with GPU rigid bodies

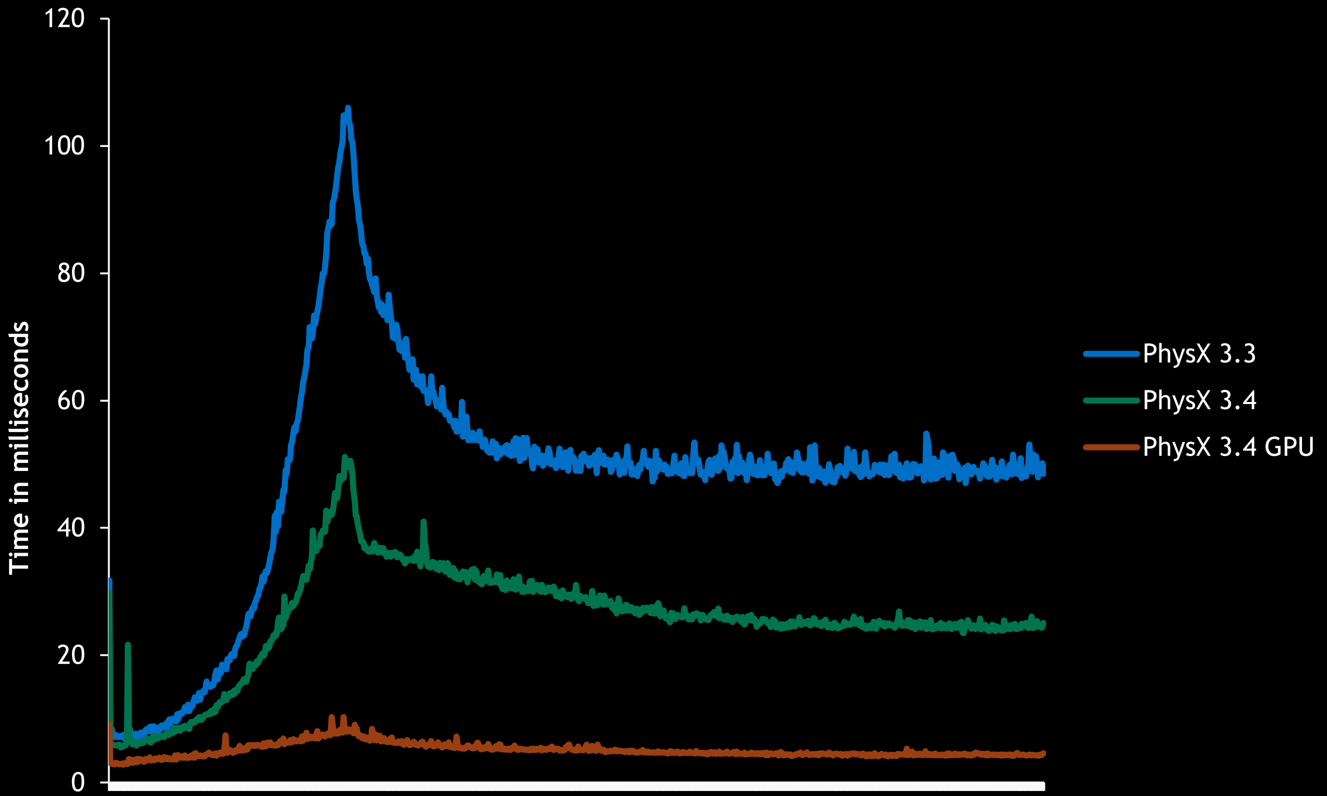
```
PxSceneDesc sceneDesc(gPhysics->getTolerancesScale());

sceneDesc.gravity = PxVec3(0.0f, -9.81f, 0.0f);

sceneDesc.cpuDispatcher= PxDefaultCpuDispatcherCreate(4);

sceneDesc.filterShader= PxDefaultSimulationFilterShader;

PxCudaContextManagerDesc cudaContextManagerDesc;

gCudaContextManager = PxCreateCudaContextManager(*gFoundation, cudaContextManagerDesc);

sceneDesc.gpuDispatcher = gCudaContextManager->getGpuDispatcher();

sceneDesc.flags |= PxSceneFlag::eENABLE_GPU_DYNAMICS;

sceneDesc.broadPhaseType = PxBroadPhaseType::eGPU;

gScene = gPhysics->createScene(sceneDesc);
```

Performance Results

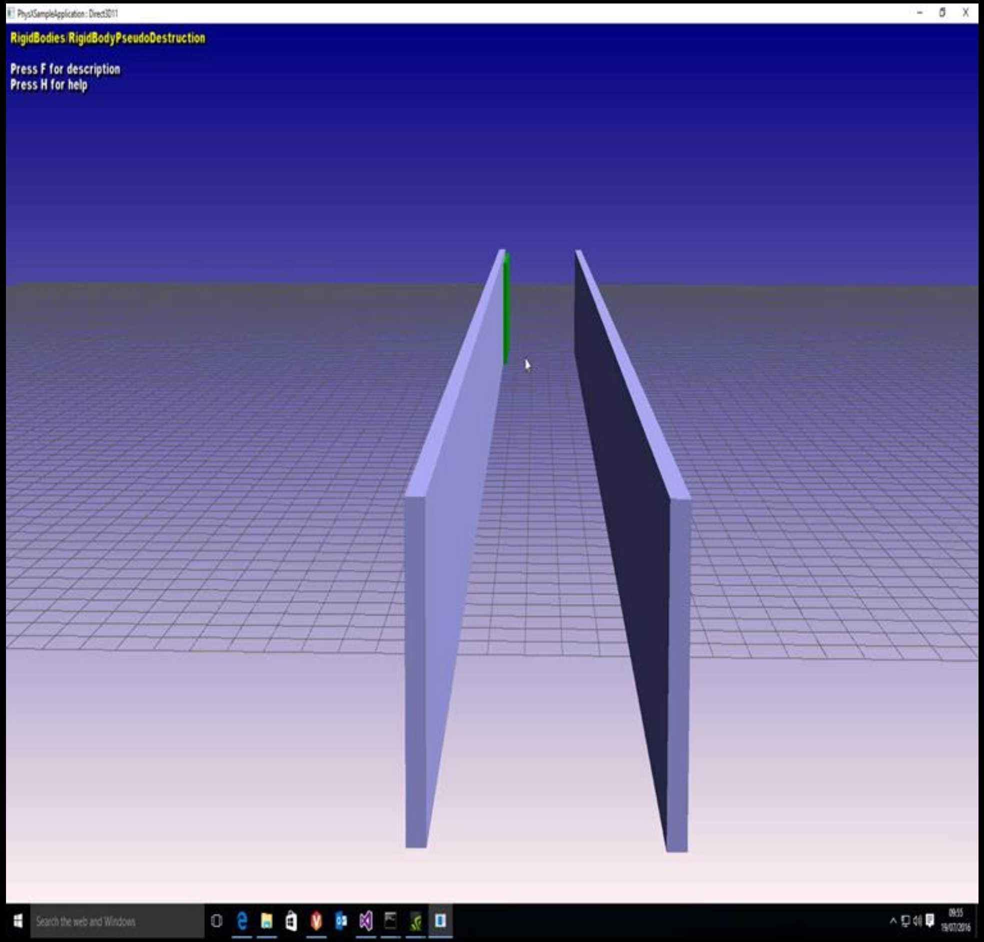
- Windows 10 64-bit
- I7-5930k
- 32GB RAM
- GTX 1080

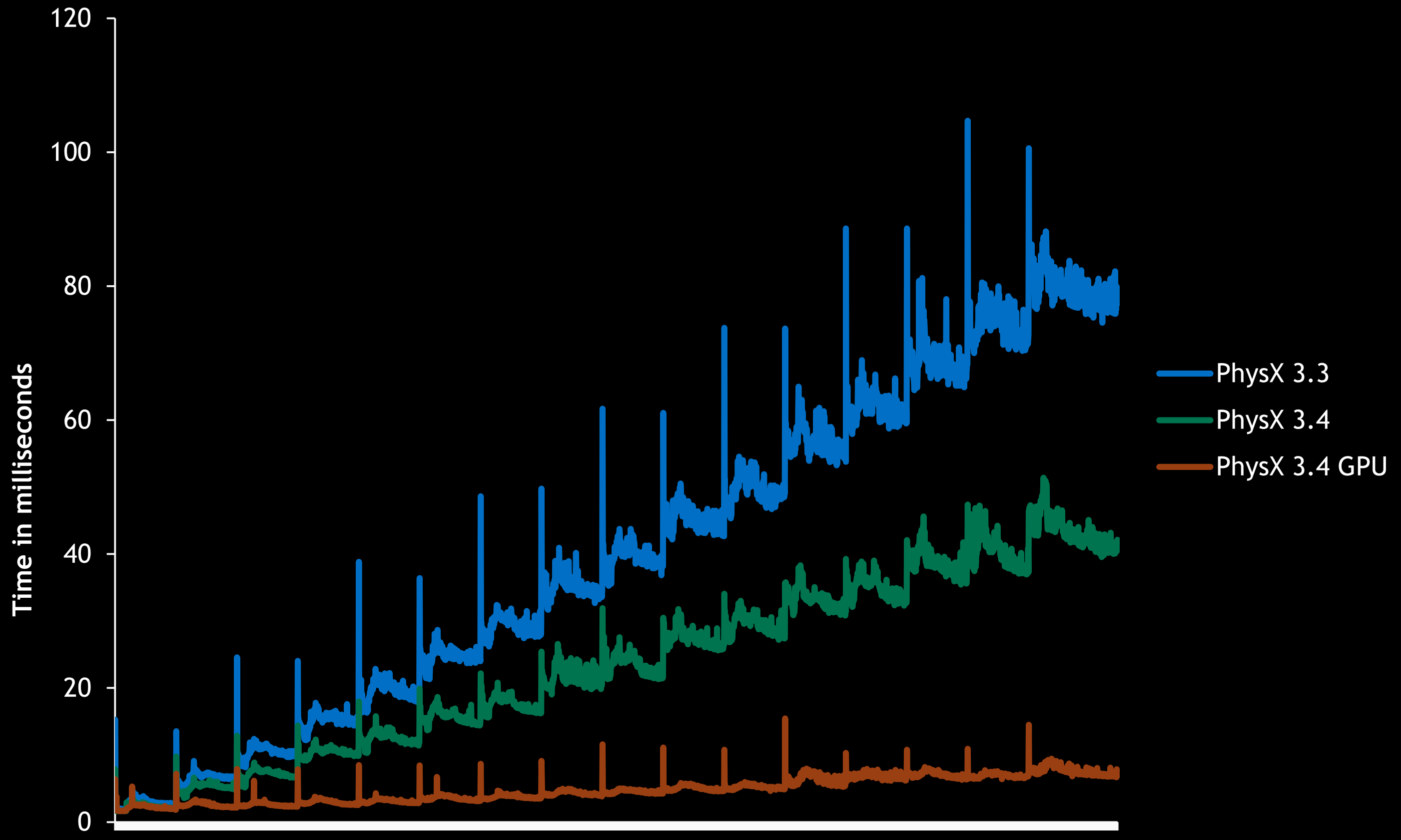
13,824 Convex Objects



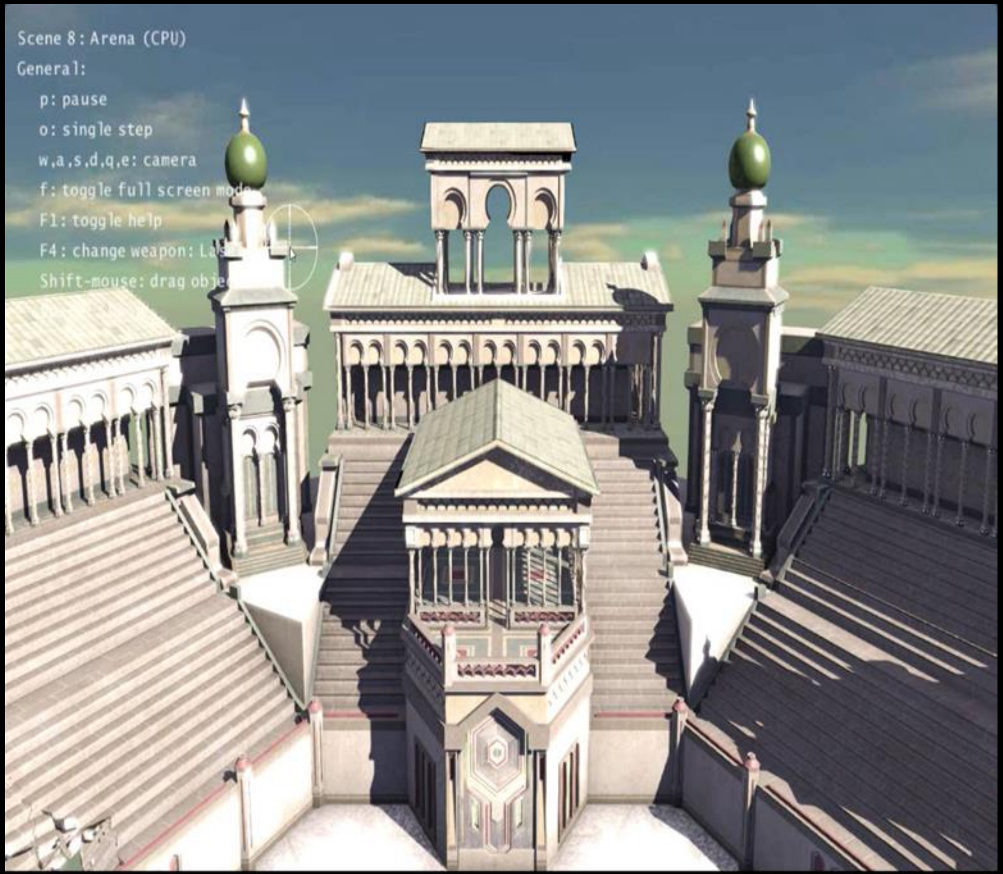


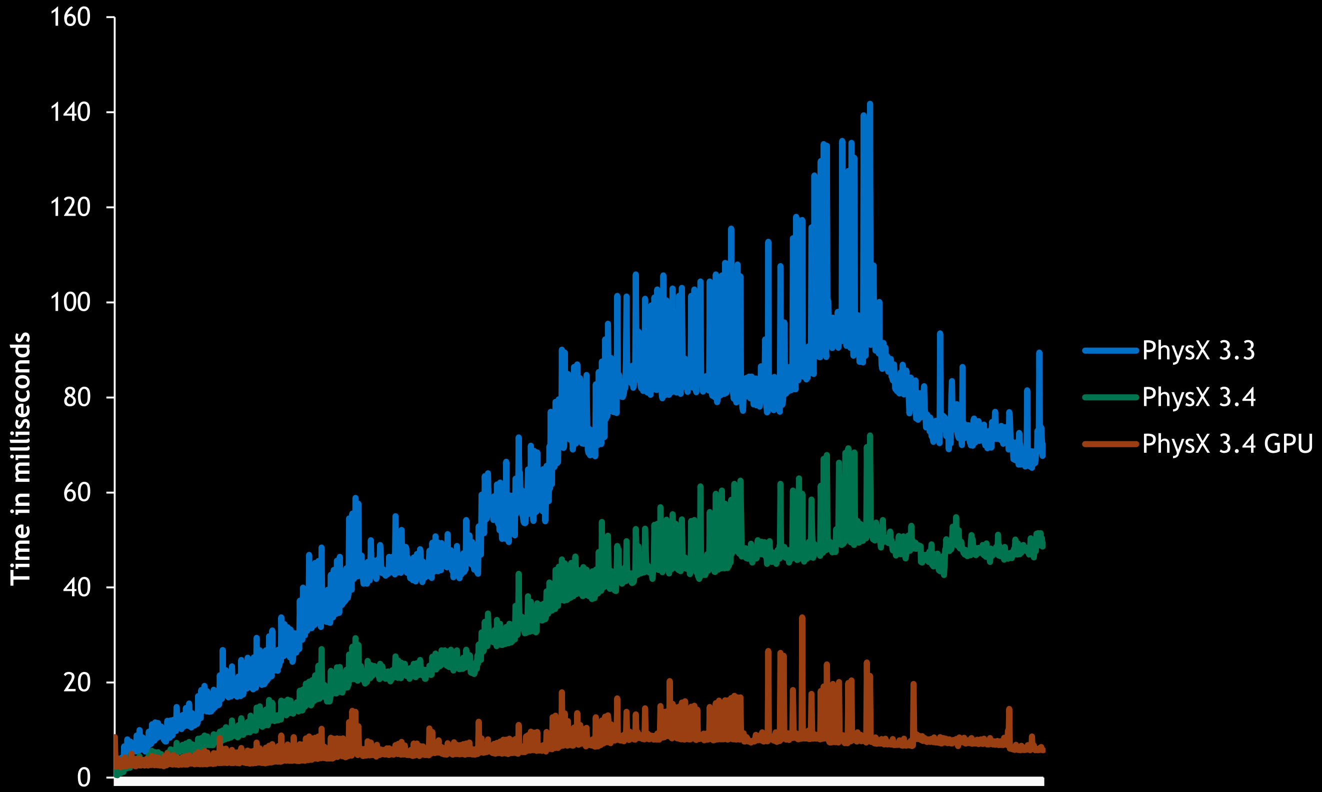
Hallway Destruction



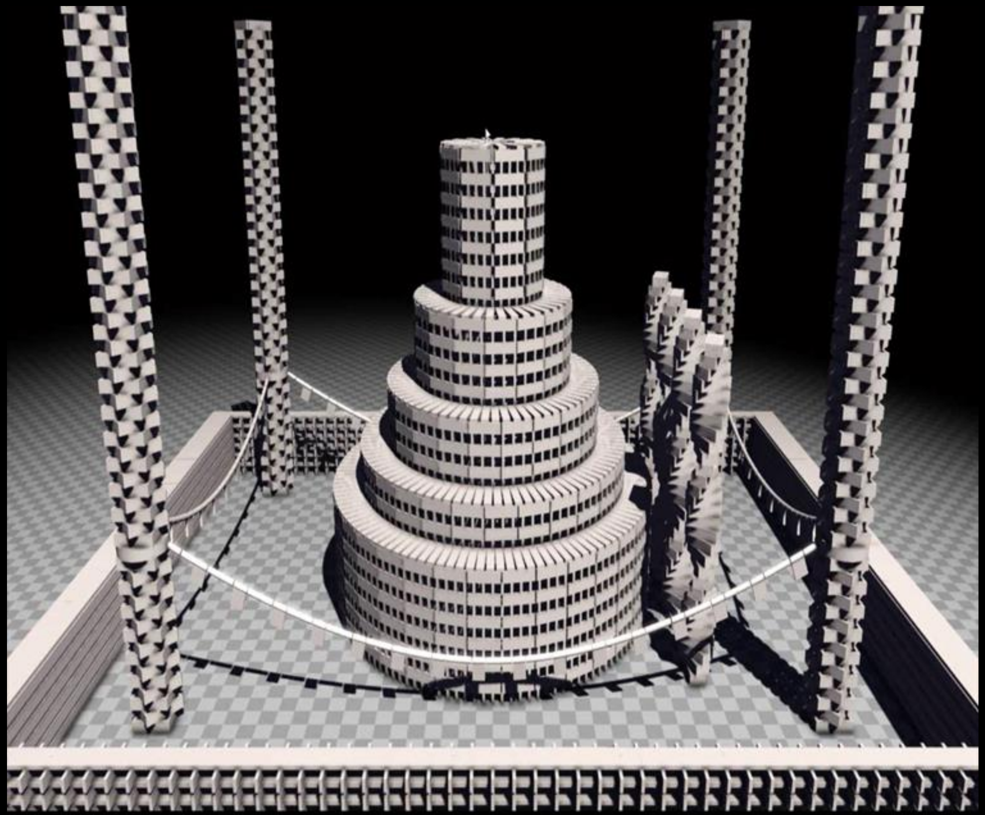


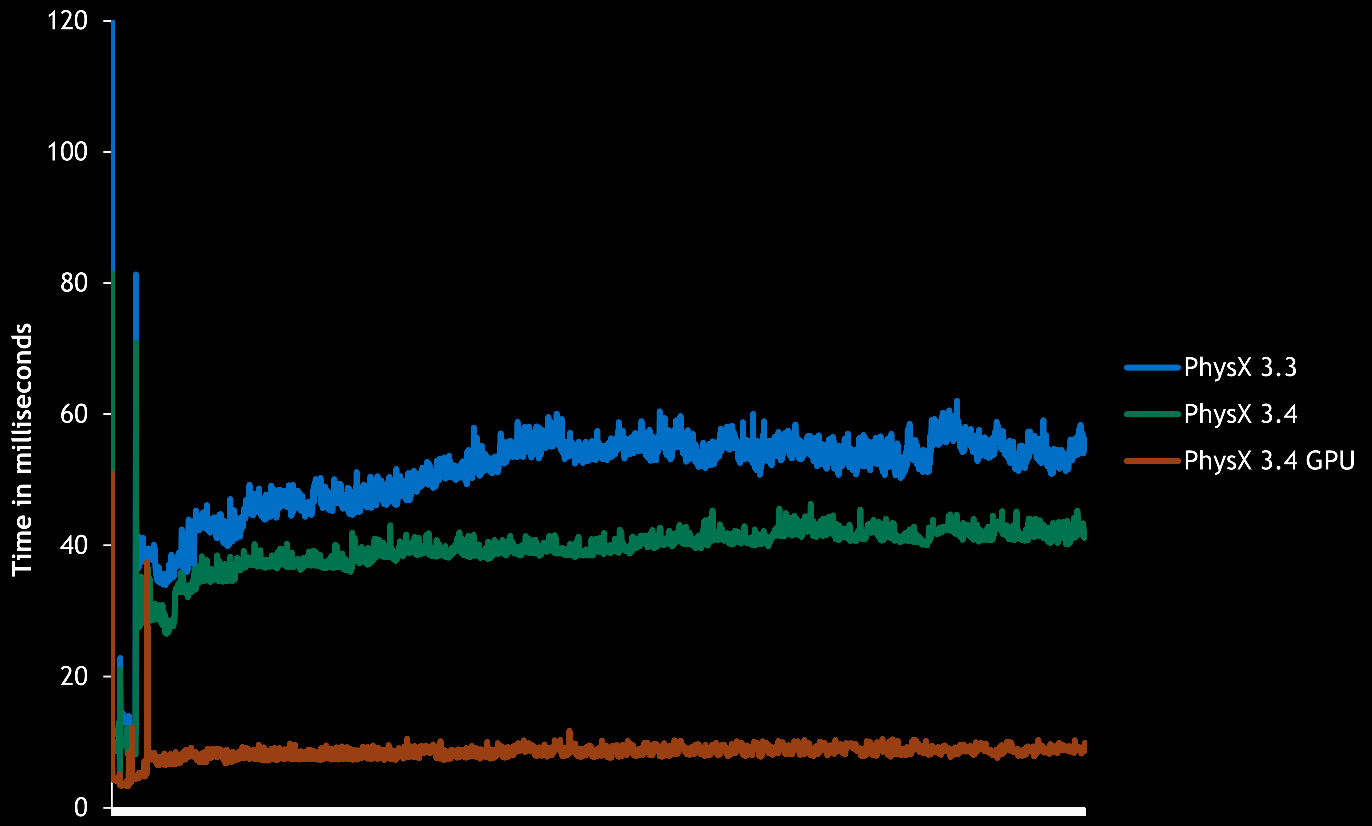
Arena Demo Destruction



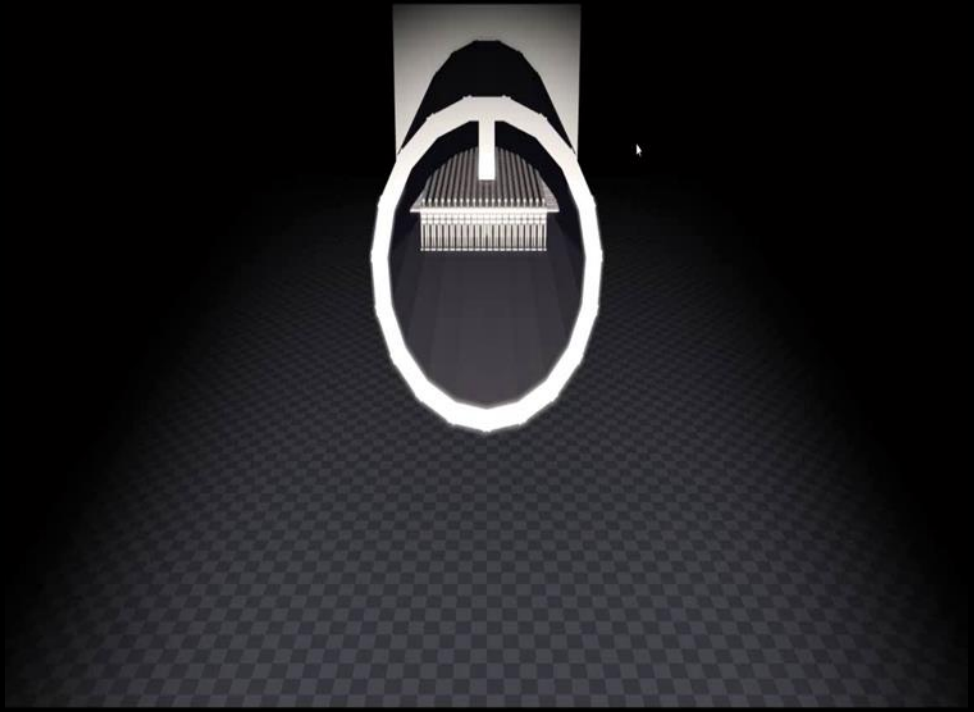


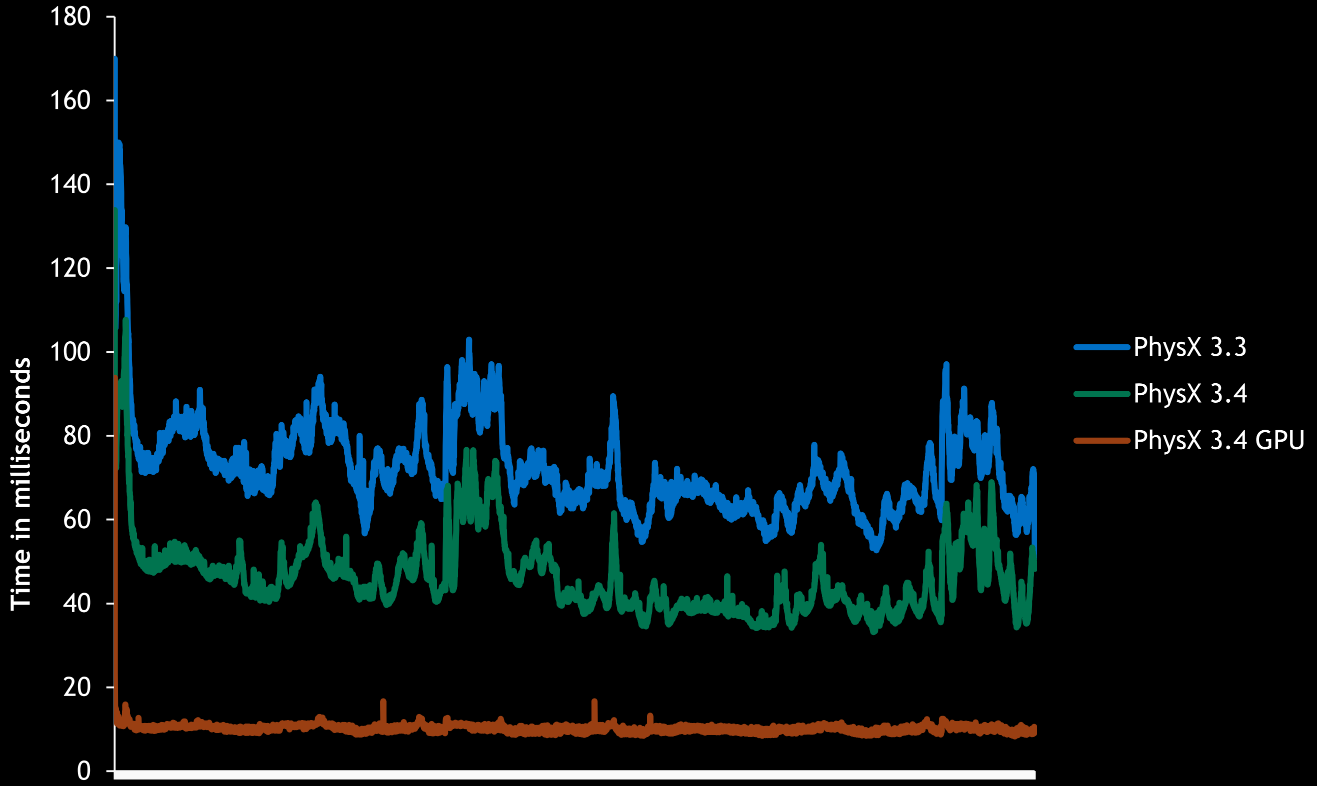
GRB Demo (Kapla Tower) 20,000 convexes



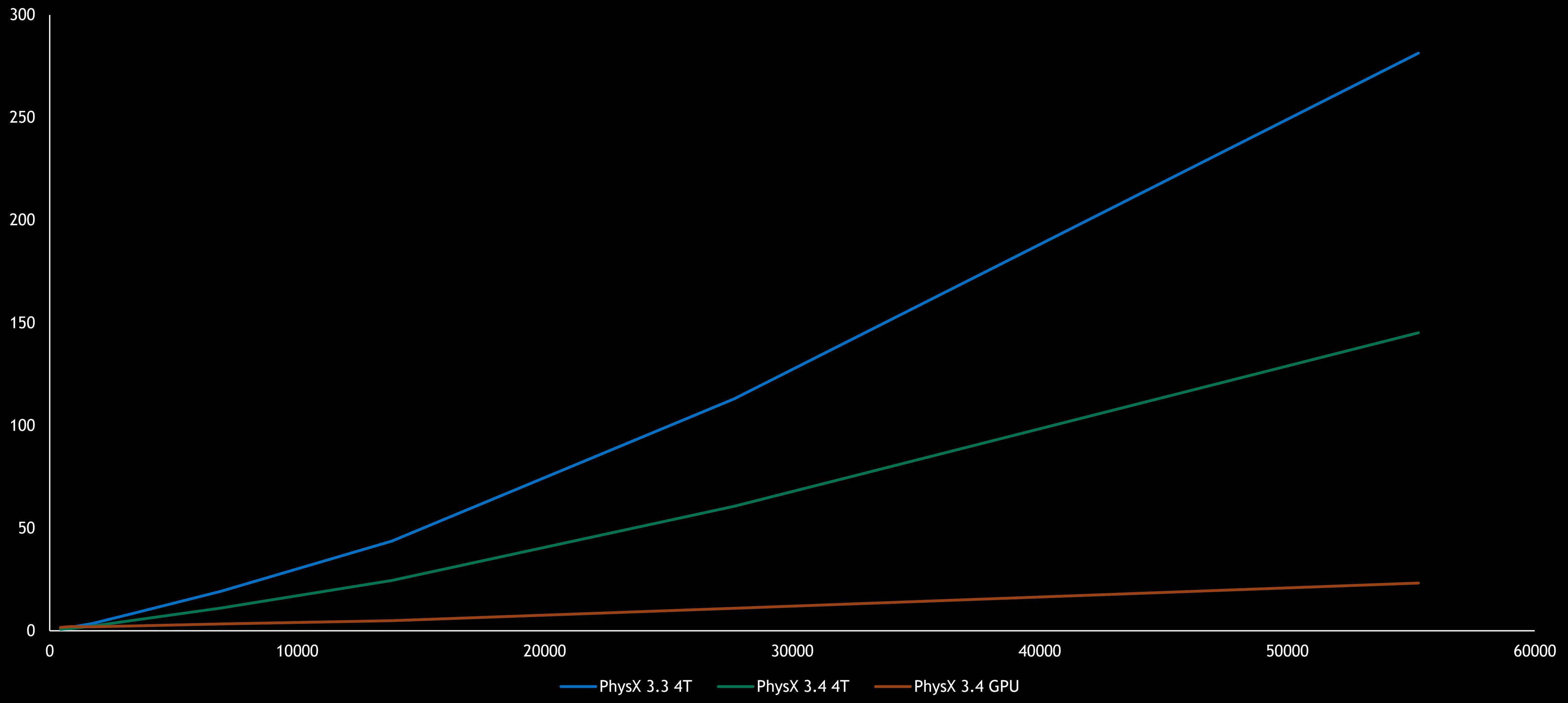


700 Ragdolls

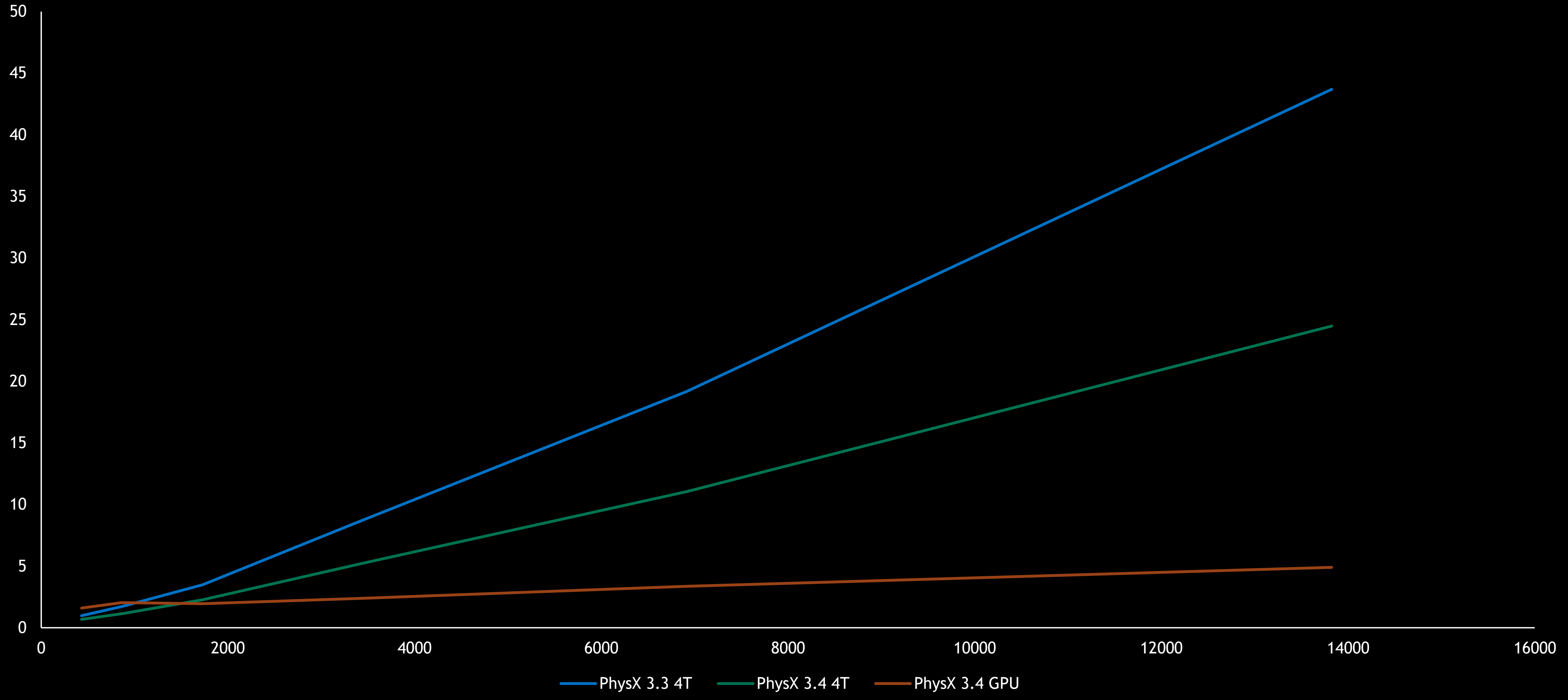




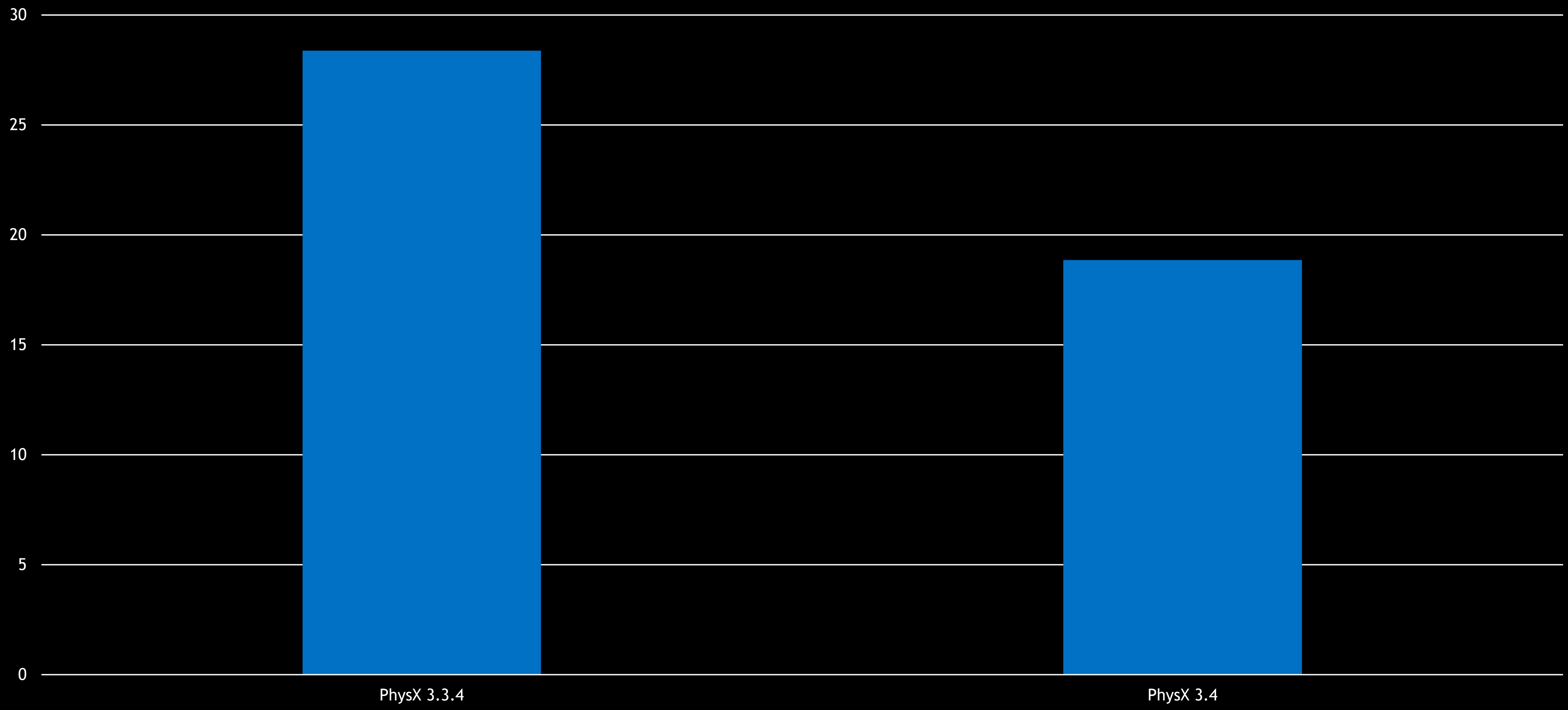
N convex objects Complexity Scaling



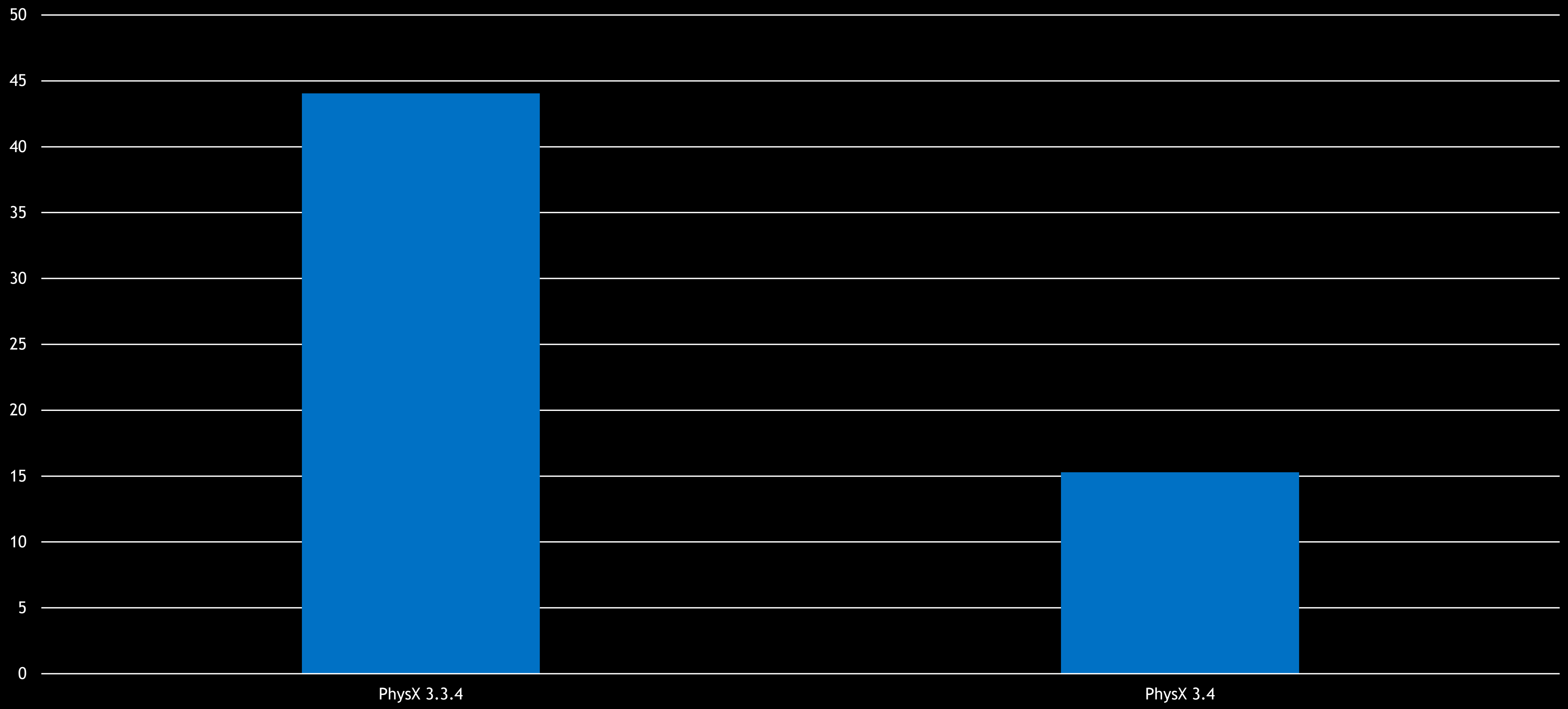
N convex objects Complexity Scaling Cont.



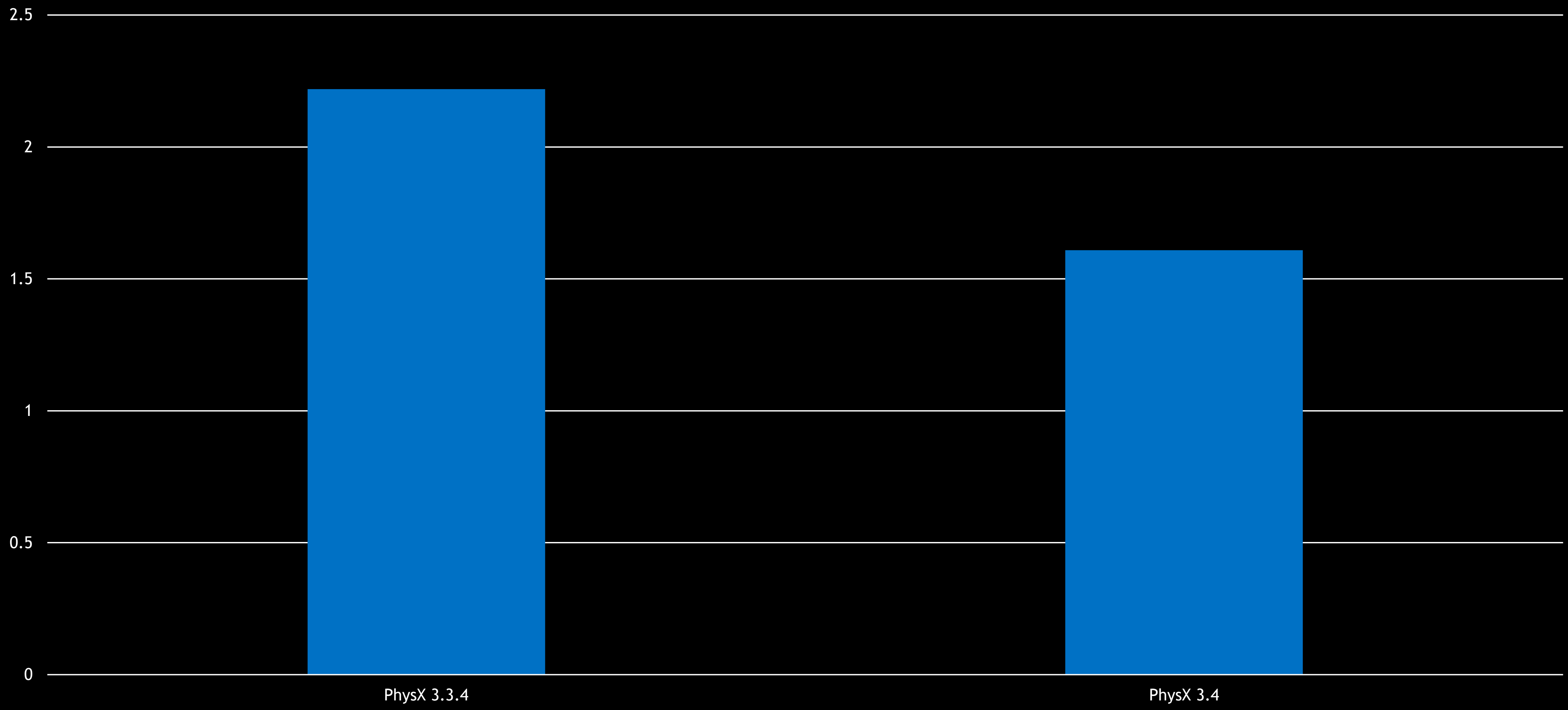
Scene Query Performance (Raycast Mesh)



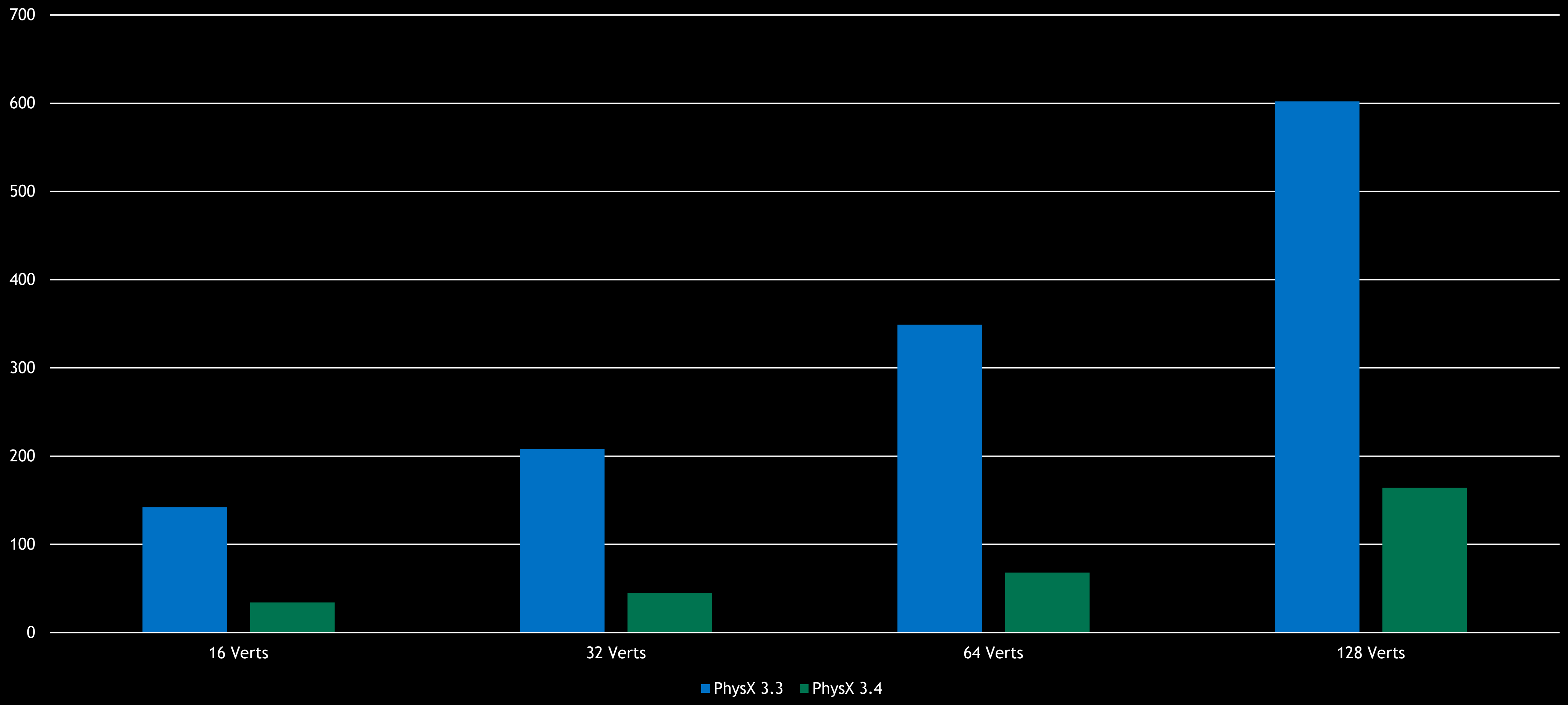
Box Sweep vs Mesh



Convex sweep vs Convex



Convex Cooking Speed Improvements



Conclusions and Future Work

- PhysX 3.4 - Full CPU source available NOW!
- Significantly faster to PhysX 3.3 across-the-board with lots of cool features
  - If you use PhysX 3.3 – you should upgrade ASAP ☺
- GPU rigid body simulation available on Windows and Linux (Kepler and above)
- GPU rigid body Future work
  - Further performance improvements
  - Improve simulation quality
  - Make feature complete

Questions?