Web Physics: A Hardware Accelerated Physics Engine for Web-Based Applications

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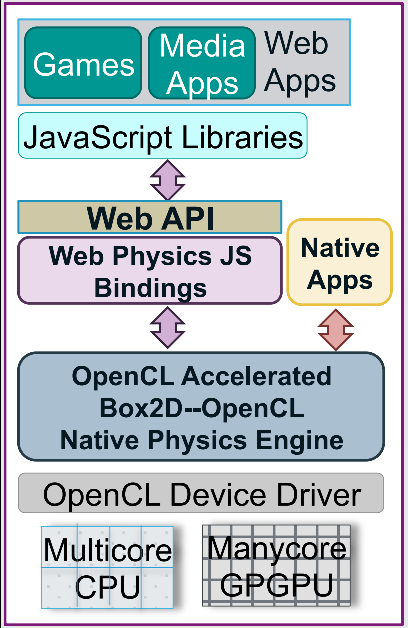
Web Physics Summary

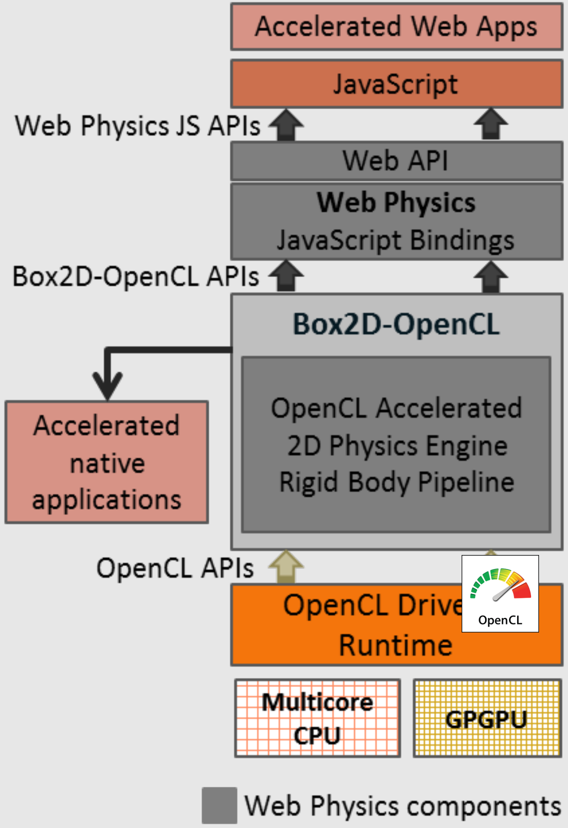
Web Physics	• Transparent access to native 2D physics engine through JS APIs. • OpenCL accelerated 2D Physics Engine (Box2D-OpenCL).
Motivation	• High performance, interactive compute & graphics apps on mobile • Transparent & efficient access to acceleration from web apps.
Goals	• Cross-platform, portable, accelerated, robust & flexible
Usages	• Real time mobile gaming; Compute intensive simulation; • Computer Aided modeling; Physical effects & realism; • Augmented Reality; Real-time big data visualization;
Approach	Hybrid Web Physics approach: • Accelerate using native multicore hardware & open parallel APIs. • Expose parallelism through JS APIs to web applications.
Accomplishments	• Web Physics JavaScript API Framework (Web Physics JS APIs) • OpenCL accelerated 2D Physics Engine (Box2D-OpenCL) • JavaScript Physics Engine (Box2DWeb 2.2.1 APIs)



Web Physics Approach

Web Physics Overview

Architectural Decision	Reasoning
Accelerated Box2D	• JS performance a concern for high compute use cases. • OpenCL parallelization API for heterogeneous multicore devices (CPU, GPU) can provide needed performance.
JavaScript bindings for physics engine APIs	• Portable Web APIs for compute intensive web apps. • Cross platform application developer support • Transparent access to accelerated library, without requiring parallelization of apps.
Modular architecture	• Incremental parallelization of physics engine pipeline • Ease of testing.
Preserve Box2D open source APIs	• Leverage existing ecosystem: To ensure that existing apps using Box2D physics engine can use Box2D-OpenCL

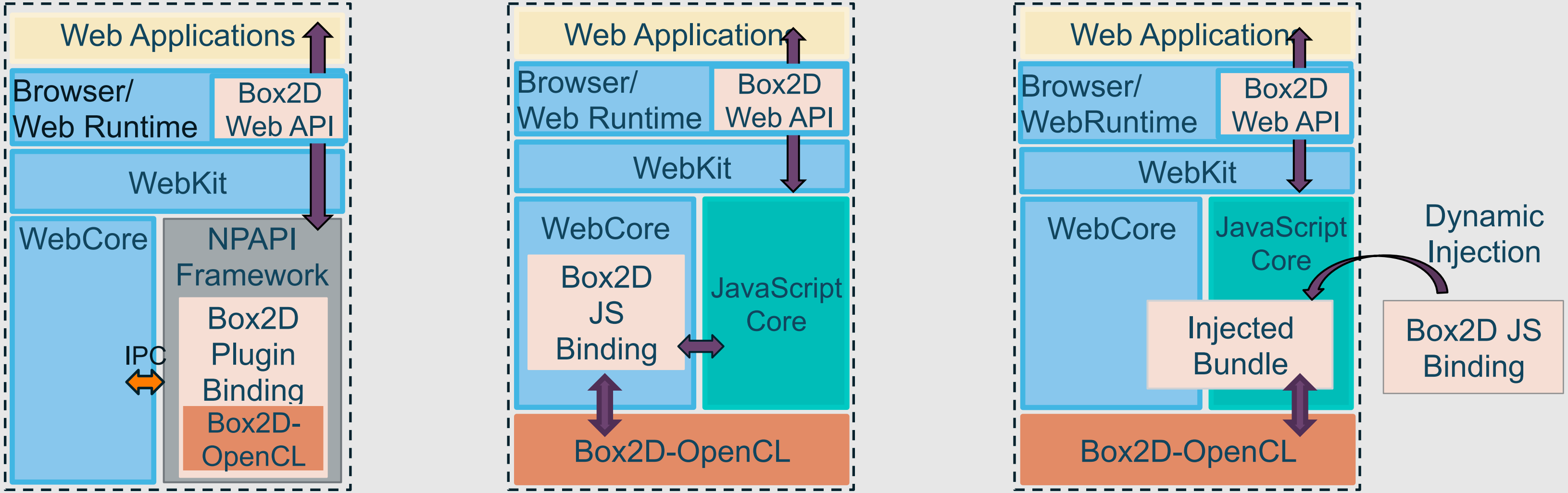


Web Physics Requirements

1. **Transparent and efficient access to acceleration on client** through JS APIs, from Web applications:
   - JS Bindings implemented in WebKit-based browser engine
2. **Near-native performance** for high compute web simulation:
   - Hybrid approach: Access to accelerated native physics engine through JS bindings
   - <= 1.5X performance impact from JS binding, relative to native physics engine
3. **Full feature support, and no API change:**
   - Complete Box2D features and API support in accelerated native physics engine
   - No API change: Box2D-OpenCL APIs should be identical to those of Box2D 2.2.1
4. **Complete JavaScript API support** in JS physics engine for benchmarking
   - Box2DWeb 2.2.1 JS physics engine supporting all Box2D 2.2.1 features.
5. **Acceleration using open parallel API for heterogeneous platforms:**
   - OpenCL accelerated physics engine for multicore CPU and GPGPU (Box2D-OpenCL)

JavaScript Bindings

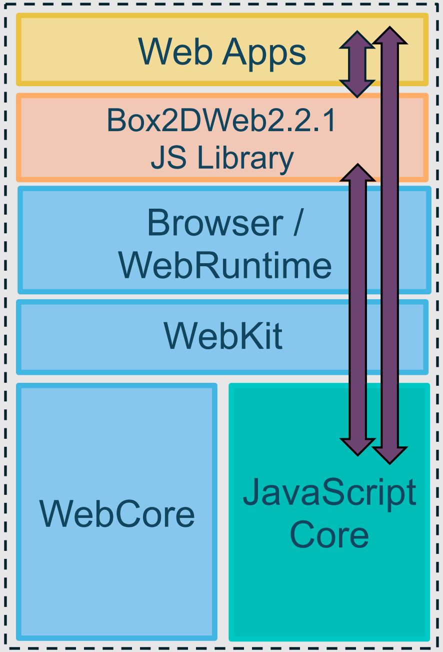
Web Physics Architectural Approaches



	Plugin-Approach	WebCore Approach	Inject Bundle
Pros	• Browser portability. • Maintainability: Less impact from physics engine changes • Code reusability	• Best comparative performance. • No IPC overhead	• Usable by native and web apps • Portability • Maintainability • No IPC overhead
Cons	• IPC communication expensive between plugin & web process	• Difficult to Maintain • More complex	• Complexity • Not Reusable across browsers

Box2DWeb 2.2.1 JavaScript Physics Engine

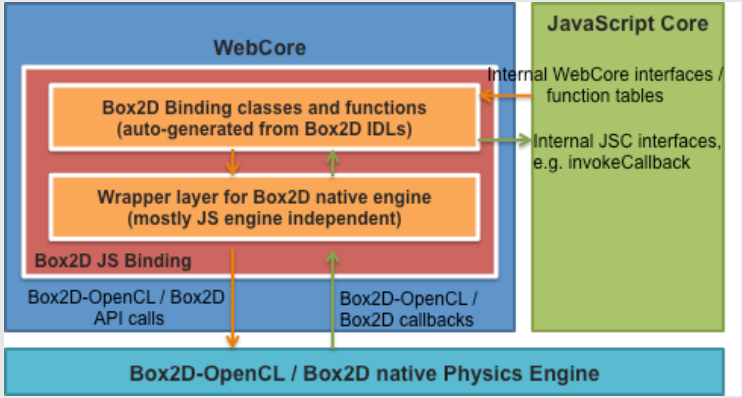
- Physics Engine written entirely in JavaScript.
- Existing open source project (box2dweb) had implemented Box2D 2.1.2 APIs.
- Box2DWeb 2.2.1 JS physics engine implements JS APIs corresponding to all Box2D 2.2.1 APIs.
- Used for benchmarking & comparative analysis.
- Currently in the process of being open sourced.



Web Physics Binding Implementation

- **IDL code generator features:**
  - Constructor overloading
  - Support for constructor-type static read-only attribute in IDL
    - Patch up-streamed to WebKit.org
    - JSC specific binding classes, functions generated from Box2D IDLs. Code generator can support JSC & V8.
- **Wrapper Layer features:**
  - Interfaces with native Box2D physics engine. A glue layer from Box2D native engine to auto-generated JS binding classes.
  - Most code is JS engine independent
  - Complete support for Box2D classes
  - 1:1 mapping to Box2D native objects
  - Preserves Box2D tree structure
  - Callback function support using Listeners
  - Supports DebugDraw

- **Performance overhead <= 1.5x** relative to Box2D
  - Includes parsing overhead of JavaScript code, and binding code overhead
- **Implementation restrictions:**
  - Strict type checking, relative to Box2DWeb
  - Native classes & functions written into IDL files, & their implementation added manually



Web Physics JS Bindings Framework

OpenCL Acceleration

Box2D-OpenCL Parallelization

Collision Detection:

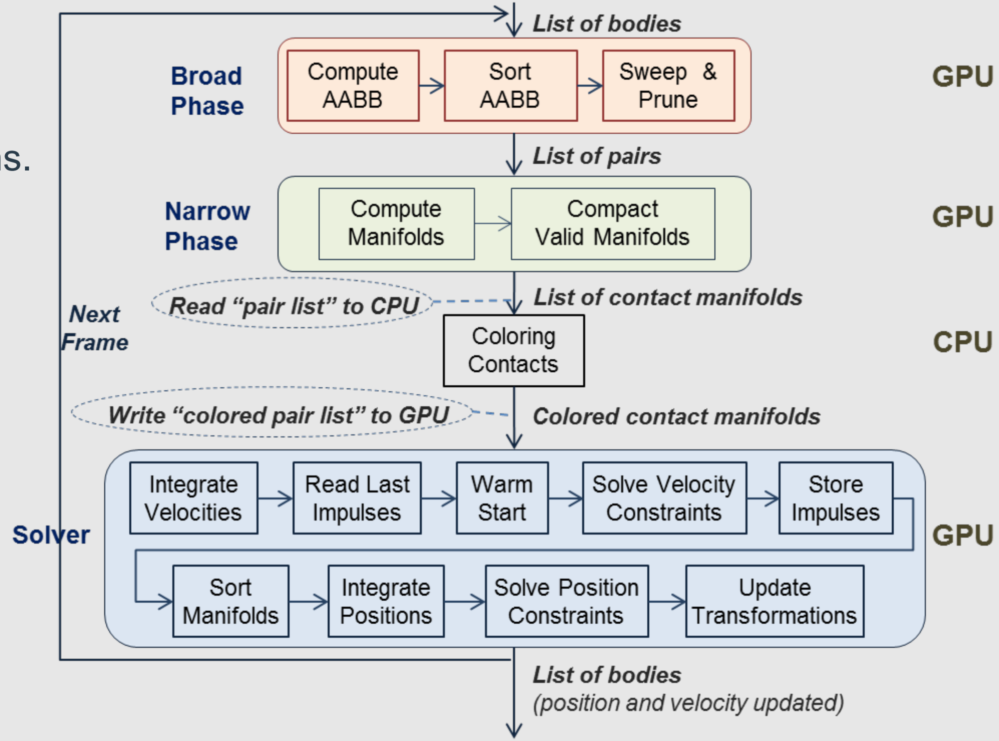
- *Broad Phase* and *Narrow Phase*.
- Enforces natural physical constraints on simulated physical objects Detects collisions.

Constraint Solver:

- Computes velocity and position constraints
- Updates velocities and positions of bodies

Benchmarking:

- *Collision Detection* & *Constraints Solver* prioritized for parallelization
- **~64%** of total time spent *in Collision Detection* stage
  - **~21%** of time spent in *Broad Phase*
  - **~43%** in *Narrow Phase*
- **~35%** of total time spent in *Solver*



Collision Detection – Broad Phase

Goal: Quickly find pairs of objects that *might* collide each other, and cull out *all* pairs that *cannot* collide each other.
Algorithm: Axis Aligned Bounding Box (AABB) used to approximate objects for fast testing

Sequential Broad Phase:

- BVH (Bounding Volume Hierarchy)
- Traverse from top to bottom
- Good for sequential programs but not efficient for parallel programs due to low parallelism in higher levels of BVH

Parallel Broad Phase:

- SaP (Sweep and Prune) [1]
- Compute an interval $[x_i, X_i]$ for each AABB O_i
- Sort all AABBs by x_min
- For all AABBs O_i, execute the followings in parallel:
  - Sweep from x_i to X_i to find all O_j with $x_j \in [x_i, X_i]$ and $i<j$
  - For each O_j, if $O_i \cap O_j \neq \varnothing$, output a pair (O_i, O_j)

[1] F. Liu, T. Harada, Y. Lee, and Y. J. Kim, "Real-time collision culling of a million bodies on graphics processing units," ACM Trans. Graph., vol. 29, no. 6, pp. 154:1–154:8, 2010.

Collision Detection – Narrow Phase

Goal: For each pair generated by BP, test whether the two objects collide or not. If collide, generate a manifold for the pair.
Algorithm: Separating Axis Theorem (SAT) used to test intersection of two objects.

Sequential Narrow Phase:
- Loop over all pairs
- Check each pair using different functions for different types (e.g. polygon-polygon, polygon-edge, circle-edge, etc.)

Parallel NP (Solution 1):
- Execute a single kernel for all pairs, using different branches for different types inside the kernel:

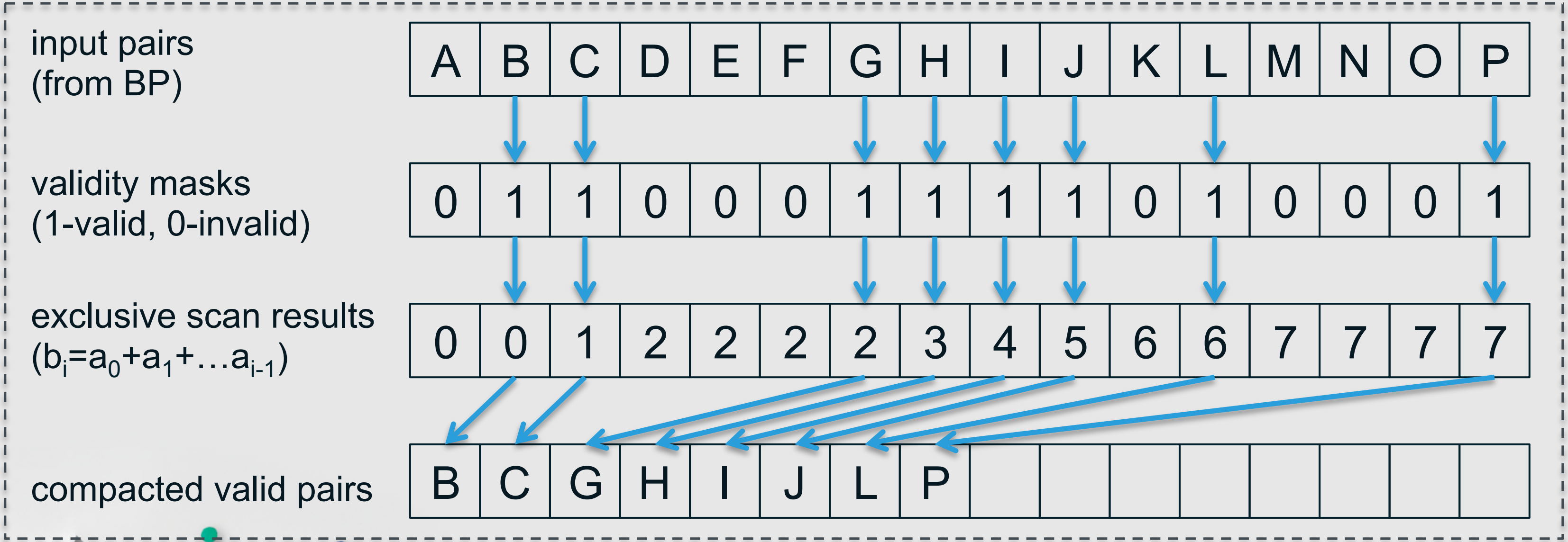
if polygon-polygon pair
    Compute for p-p type
else if circle-edge pair
    Compute for c-e type
...

Parallel NP (Solution 2):
- Execute a multiple kernels for different type of pairs, each kernel deal with one type of pair only.

➢ **Solution 2** has better performance

Collision Detection – Narrow Phase

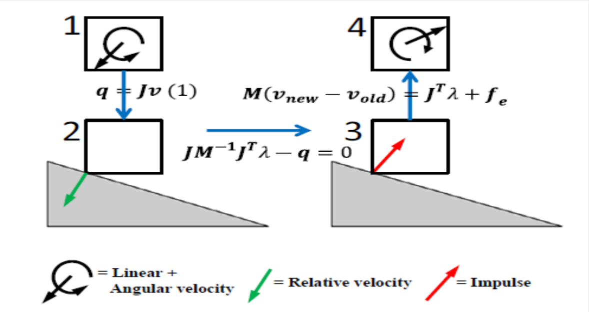
- At the end of NP stage, we compact all "valid" pairs (i.e. whose two objects collide with each other), to the head of the list for the next stage.

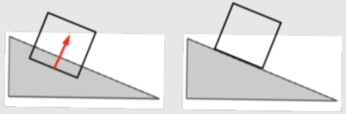


Solver

Goal: For each collided contact pair generated by collision detection, solve the physics constraints and update two bodies' velocities and positions

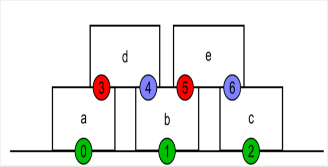
1. **Solve velocity constraints iteratively**
   - Compute relative velocities between bodies
   - Compute impulse from the relative velocities
   - Update velocities using the impulse
2. **Solve position constraints iteratively**
   - Compute penetration and convert it to impulse
   - Update positions using the impulse



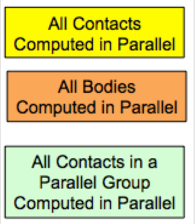


Parallel Solver:

Accelerated pipeline for parallel computation of contact constraints

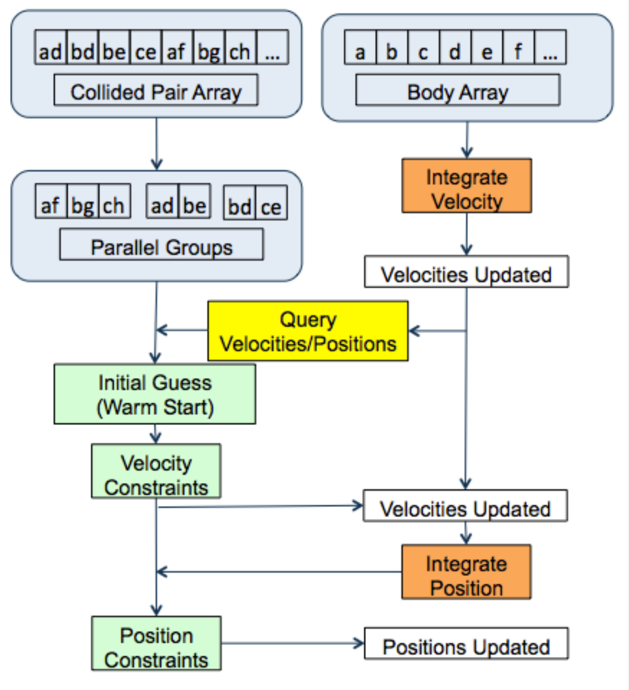


Box2D-OpenCL Parallel Solver Architecture



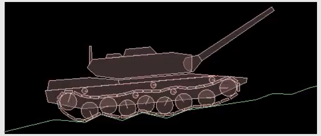
Goal: Optimize every component in solver pipeline to get the best parallel performance

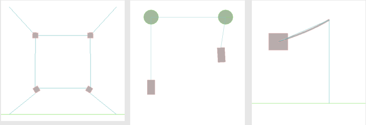
1. **Integrate velocities:** Compute all bodies in parallel
   - Apply external forces to update body velocity
2. **Cluster collided contact pairs into different contact groups**
   - All pairs in each group do not share the same body
   - Allows parallel computation in each group
3. **Impulse Initial Guess (Warm Start):** In parallel for each contact group
   - Last frame's impulse (if any) is used as an initial guess for current impulse
   - This initial guess accelerates velocity constraint solver
4. **Solve Velocity Constraints** parallel for each contact group
   - Compute impulse to solve contact constraints and update body velocities
5. **Integrate Positions** for all bodies in parallel
   - Use the new computed velocity to update the position for each body
6. **Solve Position Constraints** in parallel for each contact group
   - Compute impulse to update body positions to avoid penetration

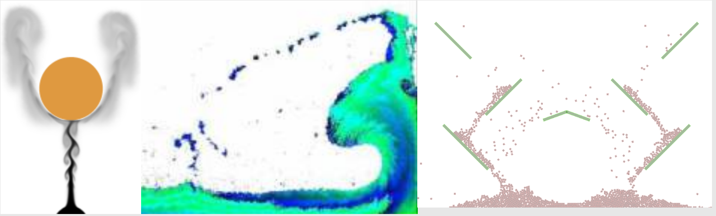


Parallel Solver Features

1. **Significant performance improvement** for high speed simulation:
   - 5X performance improvement relative sequential algorithms
2. **Full feature support** includes special joints types:
   - Parallel implementation of different joint types: Distance, Joint/Revolute, Joint/Prismatic, Joint/Pulley, Joint/Gear, joint/Rope, Joint, etc.
3. **Transparency:** Parallelization is transparent to JS app developer
   - App developers do not need to know anything about physics engine parallelization
4. **Easily extensible:**
   - Fluid, Smoke, Fracture, Sand, etc.
5. **CPU/GPU parallelization:**
   - Portable across different platforms







Experimental Results

Performance Results

Core i7 (8 cores), NVIDIA GT 650M (384 shader cores):

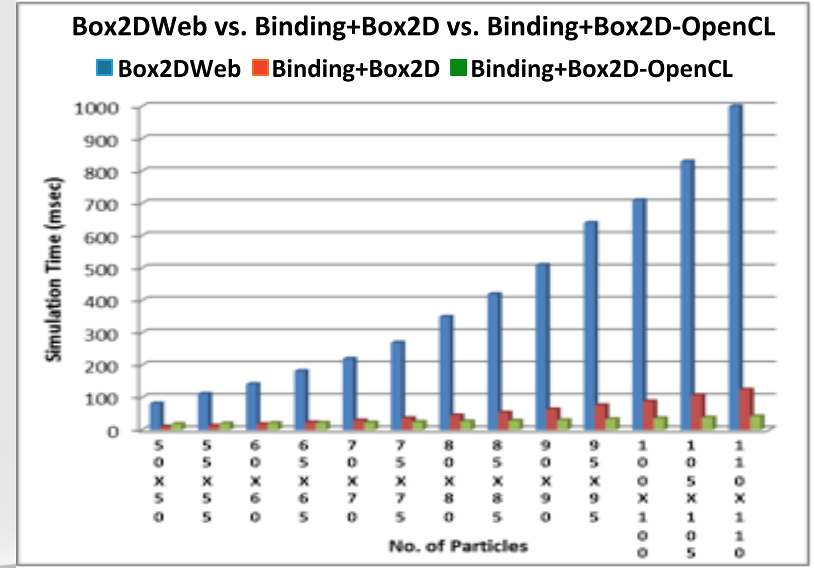
Max speedup for Box2DWeb vs. Box2D+Binding & Box2DWeb vs. Box2D-OpenCL+Binding:

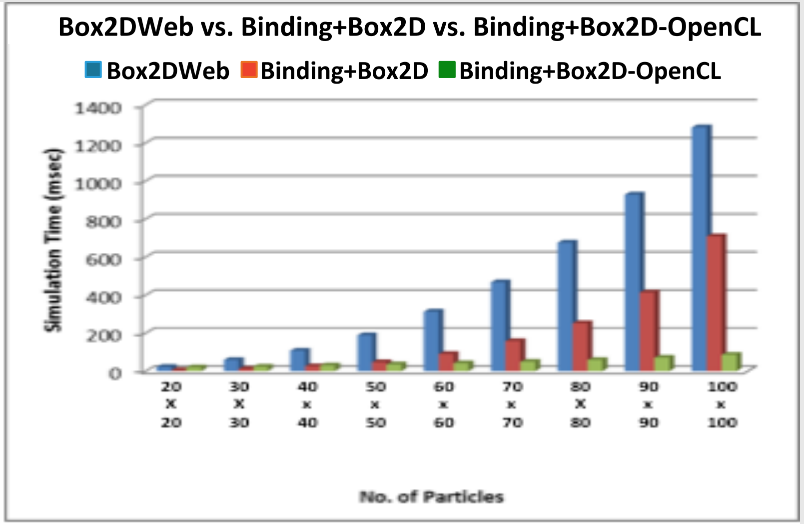
- Box2DWeb vs. Binding+Box2D: **8.39X**
- Box2DWeb vs. Binding+Box2D-OpenCL: **23.58X**

Tizen 2.2.1:

Max speedup for Box2DWeb vs. Binding+Box2D & Box2DWeb vs. Binding+Box2D-OpenCL:

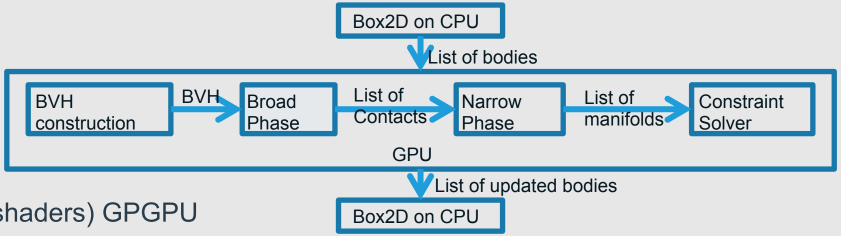
- Box2DWeb vs. Binding+Box2D: **4.75X**
- Box2DWeb vs. Binding+Box2D-OpenCL: **14.88X**



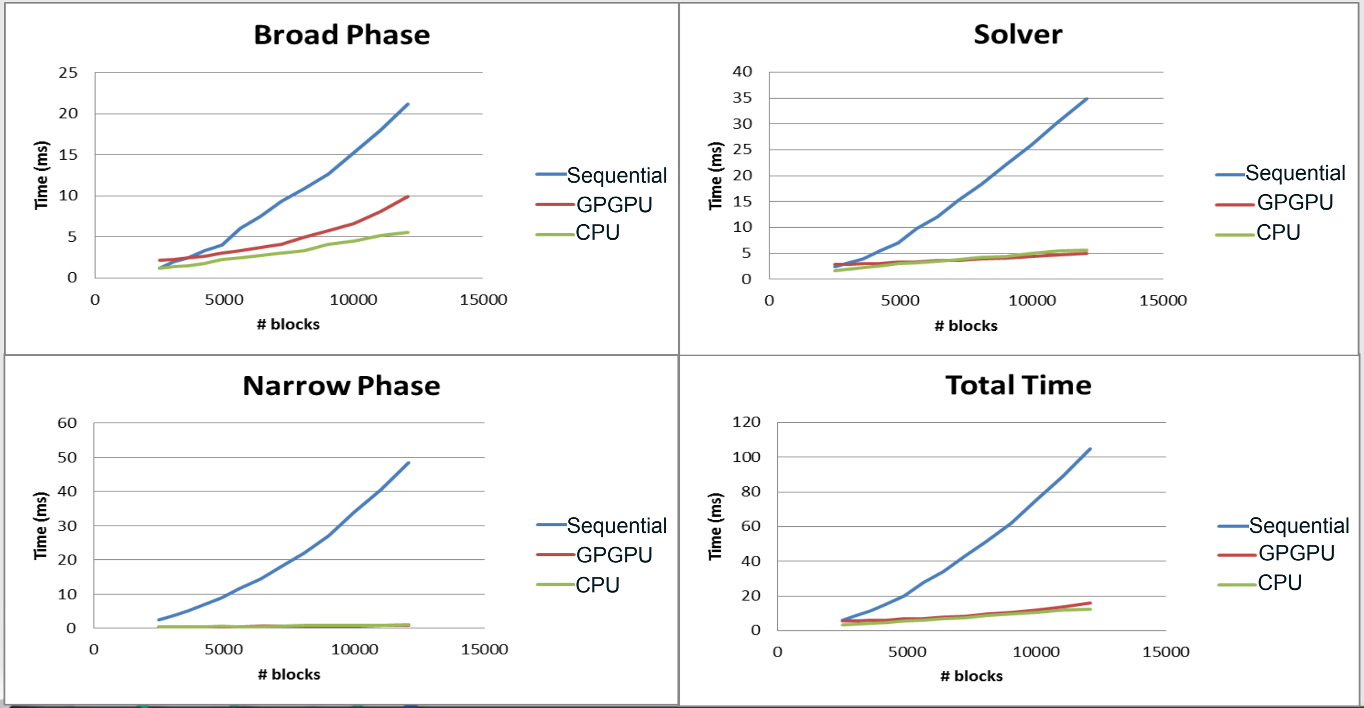


- All results are for Box2D 2.2.1 physics engine APIs

Box2D-OpenCL Acceleration



- Performance data for rigid body pipeline of OpenCL parallelized Box2D-OpenCL (without binding)
  - Tested on system with Core i7-3770K CPU, Radeon HD 7770 (640 unified shaders) GPGPU



- **Sequential** performance numbers are for Box2D.
- **GPGPU** numbers are for Box2D-OpenCL on GPGPU.
- **CPU** numbers are for Box2D-OpenCL on multicore CPU.

Conclusion

Comprehensive Web Physics Testing

Comprehensive Testing

- Testing categories:
  - Unit tests
  - Stress tests
  - Code path coverage
  - Benchmarking
  - Demo apps
  - Memory Leak tests
  - Robustness testing
- Tested on multiple platforms

Test Plan

#	Test Type	Description	
1	Unit Tests for WP JavaScript APIs	Tested for functionality and correctness	Complete
2	Stress Testing	Repetitive construction & destruction of classes. Continuous extended execution	
3	Code Path Coverage Testing	Native and JS applications to test Box2D, Box2D-OpenCL & Web Physics bindings for code coverage	
4	Benchmarking & Performance Analysis	Port of Web Physics bindings to Tizen. Benchmarking & performance analysis	
5	Demo apps for testing	Demo applications for Web Physics (Magic Sands, glBrownian, Touch&Play)	
6	Memory Leak testing	Static & dynamic testing (using Valgrind & developer tool). Box2D & Box2D-OpenCL tested with native & JS demos	
7	Robustness testing	Negative test cases. Testing with invalid and insufficient input.	

Conclusion

- **Web Physics and Box2D-OpenCL results:**
  - ✓ OpenCL accelerated physics engine, with web-based JS interface
  - ✓ Box2D-OpenCL: OpenCL accelerated rigid body pipeline. Exposes same API as Box2D
  - ✓ JS Physics Engine (Box2DWeb 2.2.1): Soon to be open sourced
  - ✓ Web Physics JS bindings & Box2D-OpenCL optimized for Tizen.
  - ✓ Box2D-OpenCL open sourced (contributions to Box2D-OpenCL are invited)
    `https://github.com/Samsung/Box2D-OpenCL`

- The presenters would like to *acknowledge* and *thank*,
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Thank you!

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