

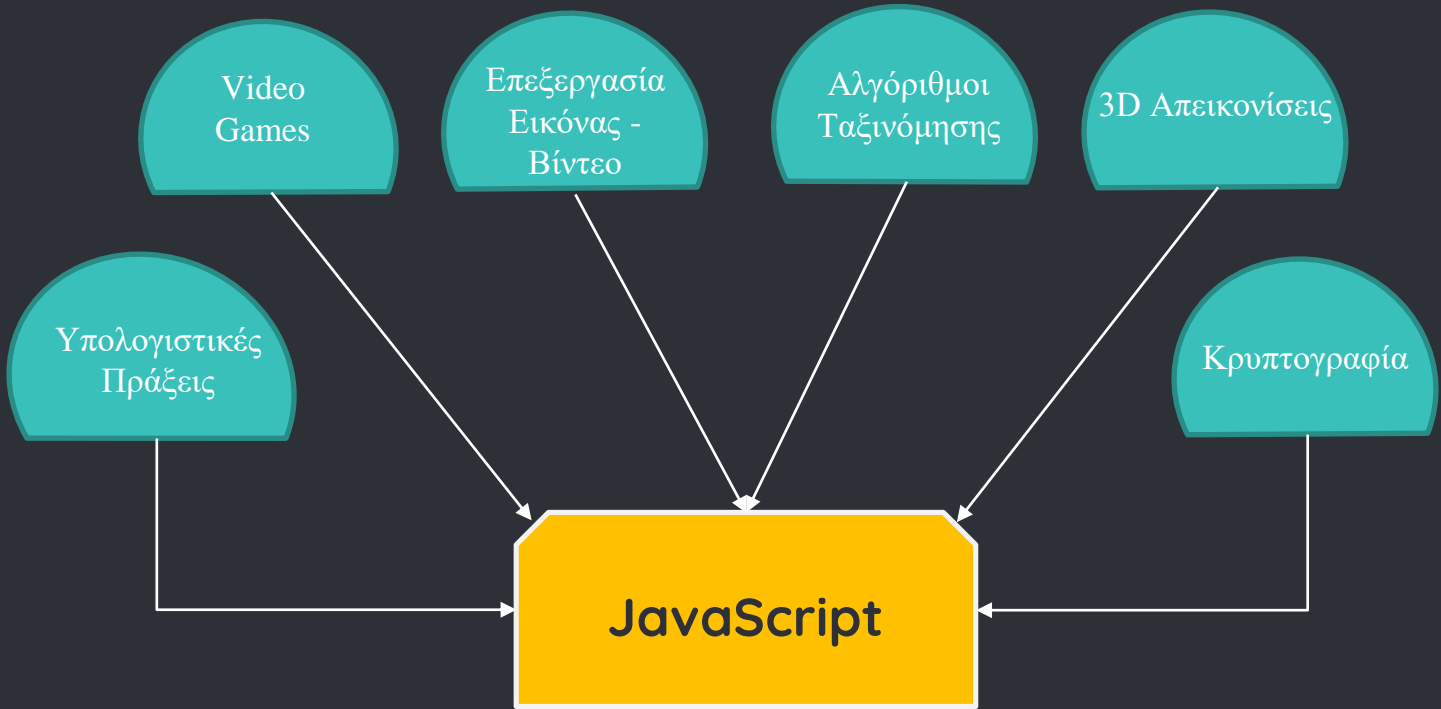
○ Συγκριτική μελέτη αλγορίθμων υψηλής υπολογιστικής ισχύος χρησιμοποιώντας web workers, WebAssembly

Πανεπιστήμιο Μακεδονίας Πρόγραμμα μεταπτυχιακών σπουδών Εφαρμοσμένης Πληροφορικής

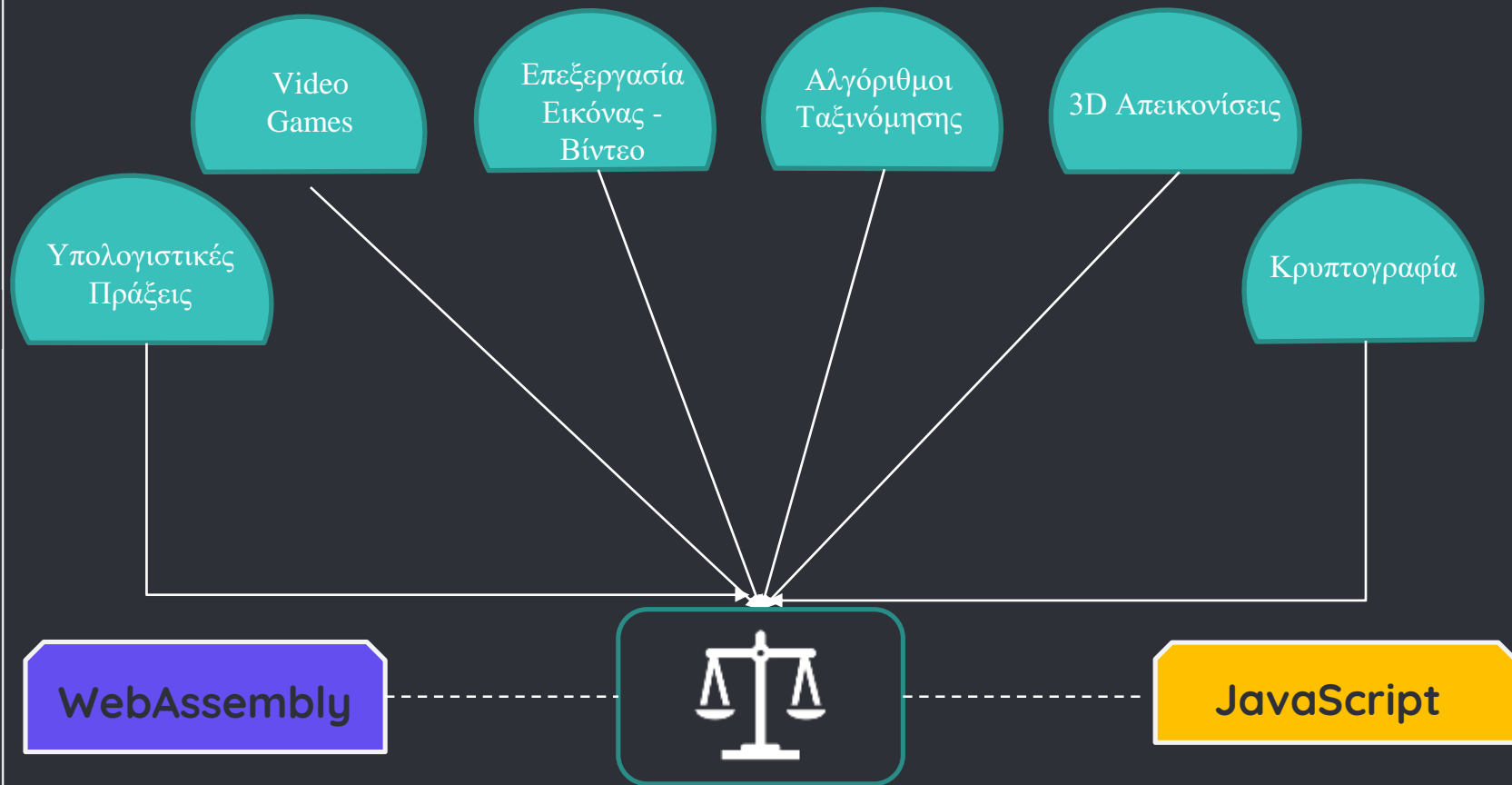


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Ημερομηνία: 11/11/2022

Πρόβλημα



Στόχος



Το Πρότυπο WebAssembly

- Γλώσσα χαμηλού επιπέδου
- Ταχύτητα, ασφάλεια και φορητότητα
- Μετατροπή από γλώσσες χαμηλού επιπέδου (C, C++, Rust)

- Ahead of time Compile
- Υποστήριξη από JS API
- Περιορισμένη πρόσβαση DOM(document object model) + Διαχείριση σκουπιδιών

Γλώσσες Προγραμματισμού

WebAssembly

1. Emscripten:

C → WASM μέσω Emscripten (glue code)

- Εκτέλεση cmd
`emcc imageGrayscale.c -s
EXPORTED_FUNCTIONS=["_imageGrayscale','_malloc','_free']" -o Grayscale.js`
- Χρήση malloc
`Module._malloc(array.length)`

2. Emscripten (Oz-O3):

Βελτιστοποιημένη Emscripten

- `emcc imageGrayscale.c -s
EXPORTED_FUNCTIONS=["_imageGrayscale','_malloc','_free']" -O3 -o
Grayscale.js`

3. JavaScript API:

C → WASM μέσω WasmFiddle | Custom Glue Code

- `WebAssembly.instantiateStreaming(fetch('grayscale.wasm')) ...`
- Δέσμευση μνήμης
`WebAssembly.instance.exports.memory.grow(15);`

JavaScript

1. Native JavaScript

2. Native JavaScript WebWorker

C

1. Native C

Διάγραμμα Συγκριτικής Μελέτης

Επίπεδο 1 Κατηγορίες Αλγορίθμων

- Αριθμητικών Υπολογισμών
- Ταξινόμησης
- Επεξεργασίας Εικόνας

Αριθμητικών Υπολογισμών

1. Ακολουθία Fibonacci
2. Πολλαπλασιασμός Διπλής Ακρίβειας
3. Πολλαπλασιασμός Ακεραίων Αριθμών
4. Πολλαπλασιασμός Πινάκων
5. Πρώτοι Αριθμοί

Ταξινόμησης

1. Φυσαλίδα
2. Ταχυταξινόμηση
3. Αντιστροφή Πινάκων

Επεξεργασία Εικόνας

1. Grayscale
2. Convolution
3. Threshold

Επίπεδο 2 Γλώσσες Προγραμματισμού (Παράγωγα)

Native JavaScript JS	WebAssembly Emscripten WA	WebAssembly JavaScript API WA	Native C C	WebAssembly Emscripten (O3) WA	WebAssembly Emscripten (Oz) WA	JavaScript WebWorker JS
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Επίπεδο 3 Προγράμματα Περιήγησης (State Hot)



Επίπεδο 4 Υπολογιστές Εκτέλεσης










Επίπεδο 5



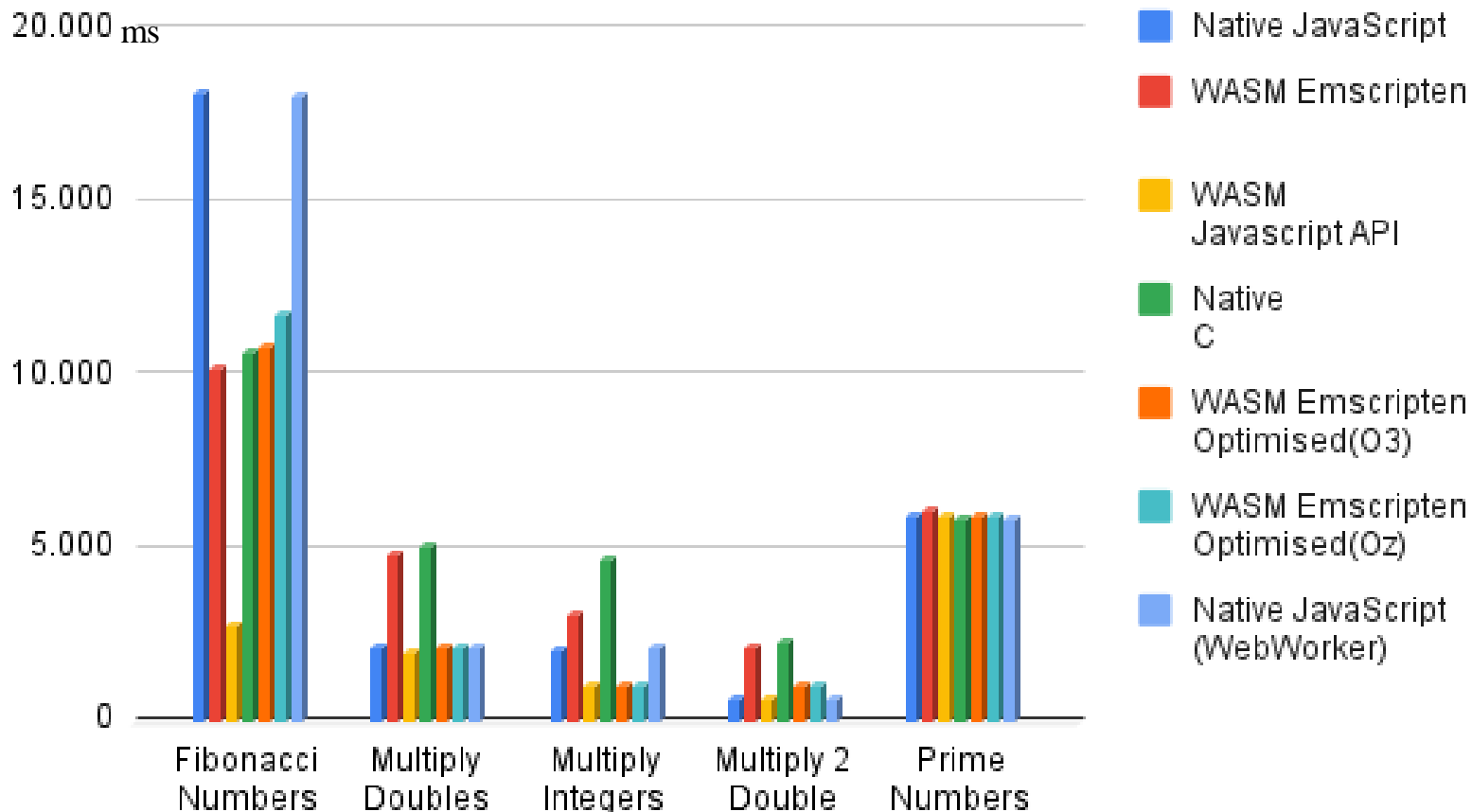
1. **Desktop** (Windows 10 pro)
CPU: AMD Ryzen 5 3600X - 3.8GHz.
RAM: 16,0GB - 1596 MHz
2. **Laptop** (Windows 10 pro)
CPU: INTEL Core i5 7200U - 2.50GHz.
RAM: 8 GB - 1064 MHz
3. **Mobile** (IOS 15.5)
CPU: A13 Bionic Chip - 2.6 GHz.
RAM: 6 GB.

Πίνακες και Γραφήματα
Γεωμετρικός μέσος 30 αποτελεσμάτων

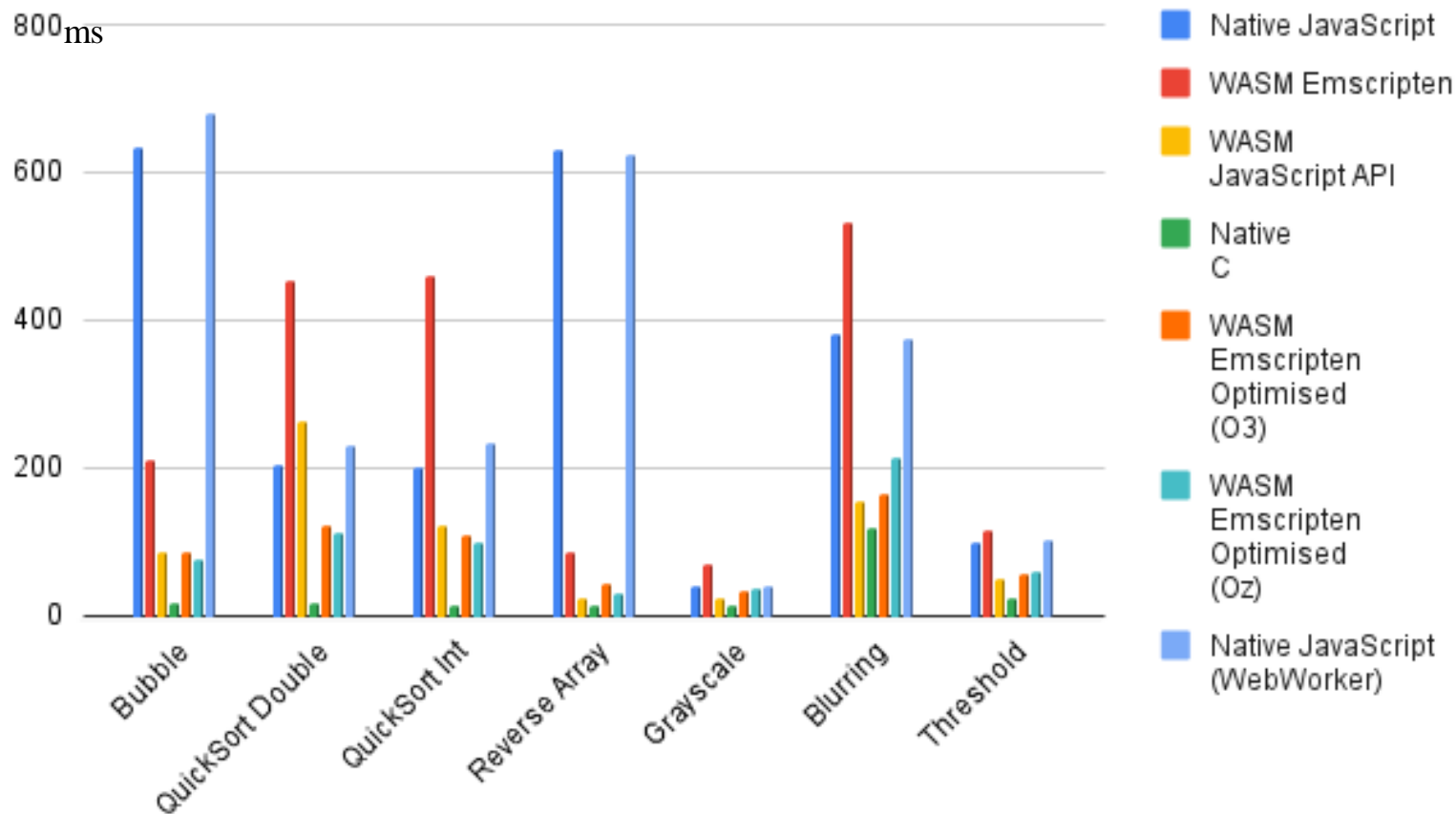
Αποτελέσματα Μετρήσεων σε Desktop

Algorithms Desktop Chrome	Native JavaScript 	WASM Emscripten 	WASM JavaScript API 	Native C 	WASM Emscripten Optimised (O3) 	WASM Emscripten Optimised (Oz) 	Native JavaScript (WebWorker) 
Fibonacci	18.167	10.216	2.809	10.663	10.806	11.763	18.128
Multiply Doubles	2.152	4.872	2.039	5.121	2.164	2.154	2.142
Multiply Integers	2.056	3.089	1.082	4.679	1.094	1.074	2.146
Multiply Double Arrays	0.629	2.173	0.682	2.342	1.046	1.026	0.629
Prime Numbers	5.945	6.096	5.925	5.647	5.981	5.988	5.842
Bubble Sort	0.635	0.212	0.085	0.017	0.085	0.077	0.680
QuickSort Double	0.205	0.453	0.263	0.018	0.124	0.113	0.231
QuickSort Int	0.202	0.459	0.124	0.014	0.111	0.100	0.233
Reverse Array	0.630	0.086	0.025	0.016	0.045	0.032	0.625
Grayscale	0.040	0.069	0.023	0.014	0.033	0.038	0.042
Blurring (Convolution)	0.381	0.534	0.157	0.121	0.165	0.214	0.374
Threshold	0.101	0.117	0.051	0.023	0.058	0.060	0.104

Chrome Hot - Numerical Computing - Desktop



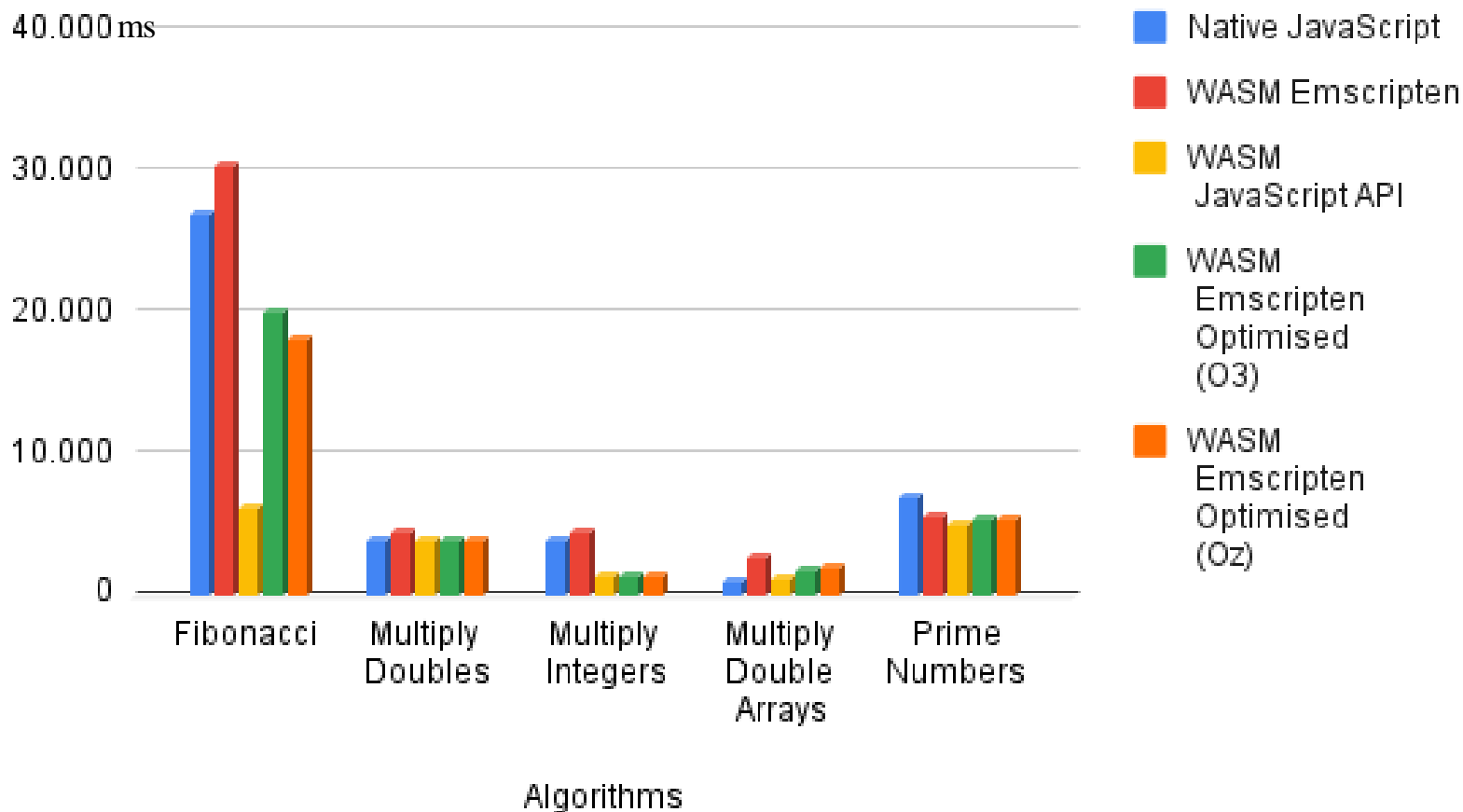
Chrome Hot - Sorting, Image Processing - Desktop



Αποτελέσματα Μετρήσεων σε Laptop

Algorithms Laptop Chrome	Native JavaScript JS	WASM Emscripten WA	WASM JavaScript API WA	WASM Emscripten Optimised (O3) WA	WASM Emscripten Optimised (Oz) WA
Fibonacci	27.159	30.487	6.185	20.154	18.254
Multiply Doubles	3.931	4.515	3.925	3.954	3.918
Multiply Integers	3.939	4.427	1.476	1.490	1.485
Multiply Double Arrays	1.087	2.846	1.301	1.820	1.925
Prime Numbers	6.956	5.624	5.024	5.547	5.514
Bubble Sort	1.038	0.322	0.128	0.125	0.112
QuickSort Double	0.432	0.544	0.335	0.172	0.176
QuickSort Int	0.416	0.536	0.175	0.152	0.152
Reverse Array	1.081	1.254	0.065	0.067	0.054
Grayscale	0.075	0.106	0.045	0.062	0.076
Blurring	0.654	0.742	0.295	0.292	0.368
Threshold	0.242	0.234	0.154	0.149	0.159

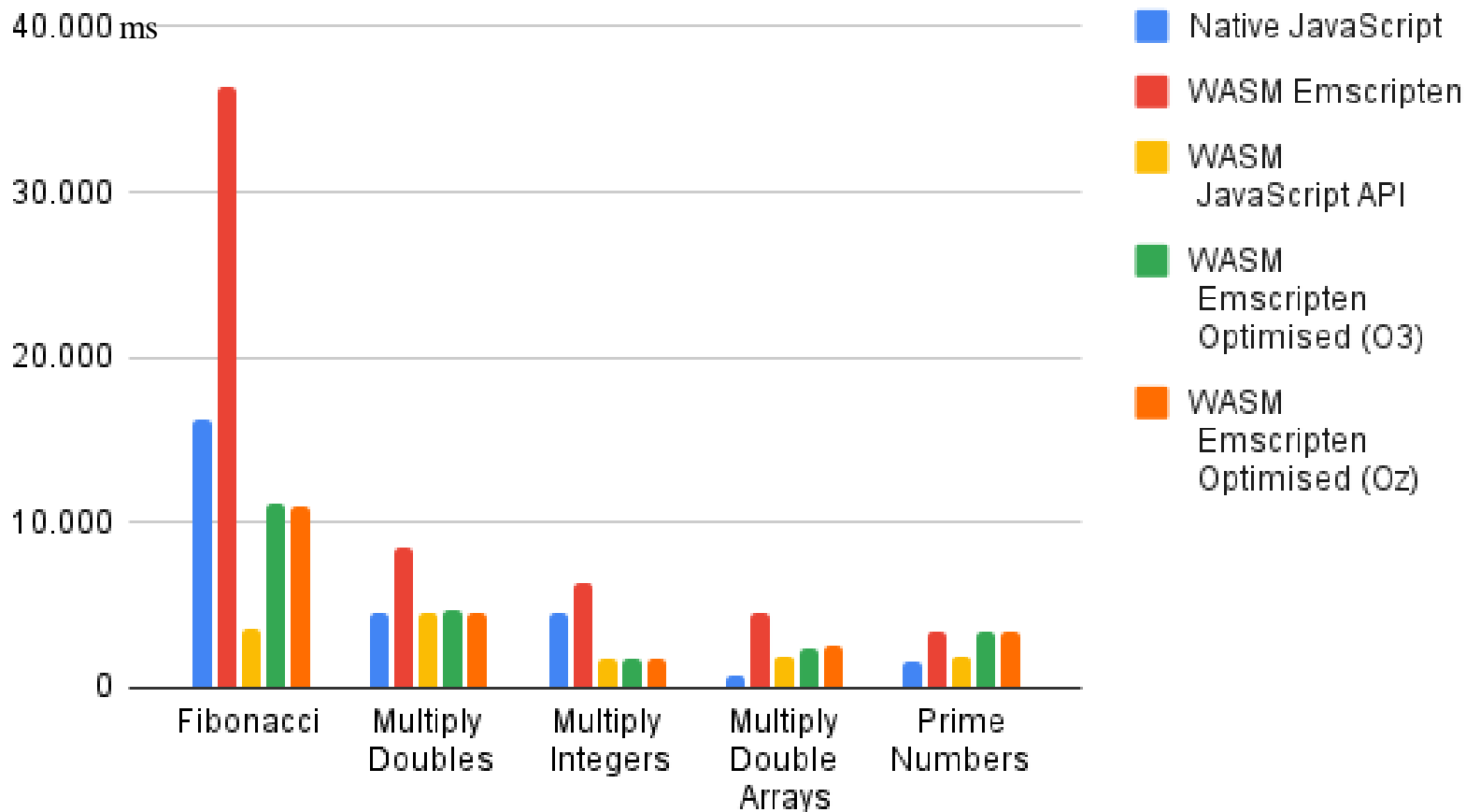
Chrome Hot - Numerical Computing - Laptop



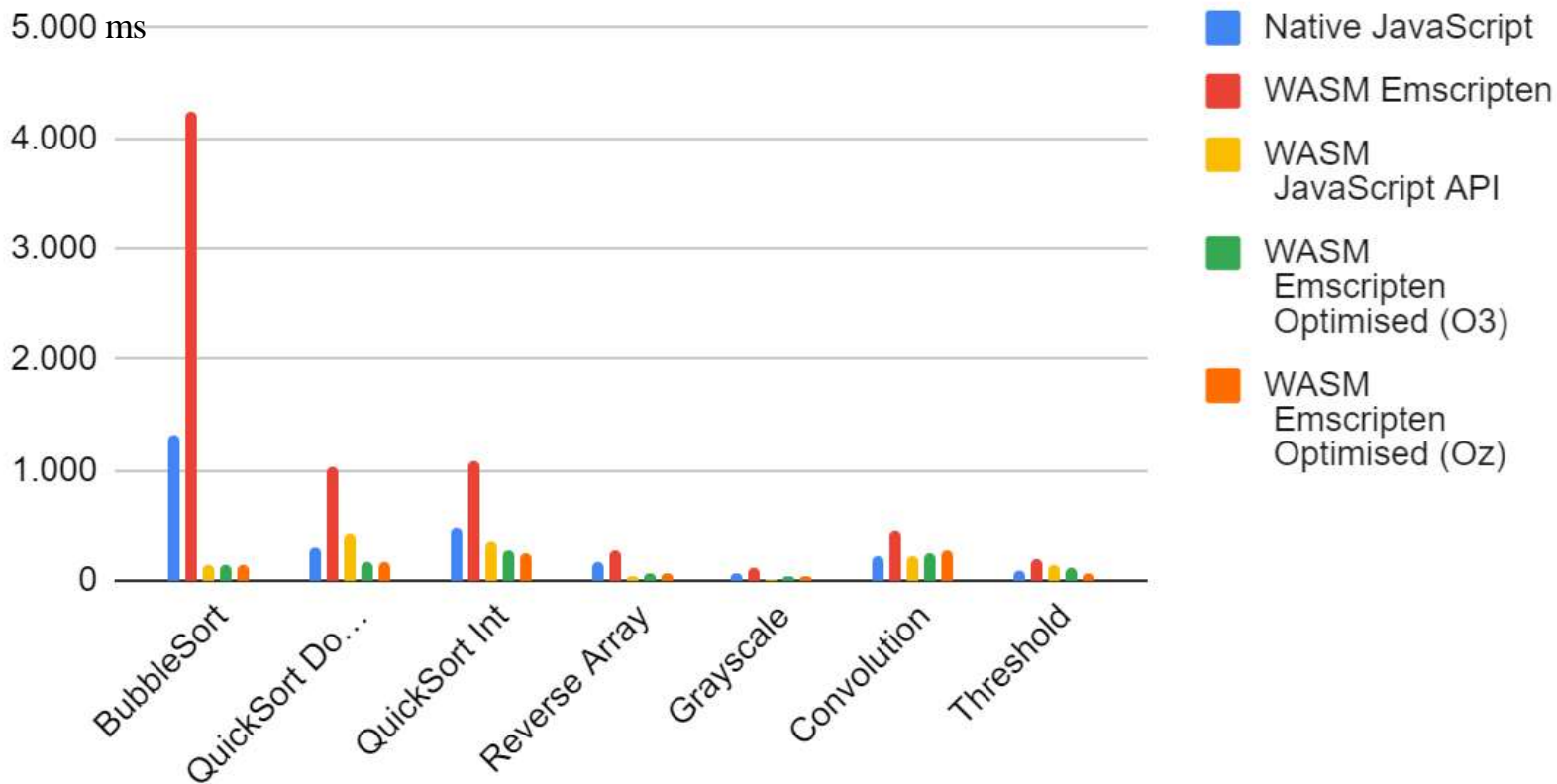
Αποτελέσματα Μετρήσεων σε Mobile

Algorithms Mobie Chrome	Native JavaScript JS	WASM Emscripten WA	WASM JavaScript API WA	WASM Emscripten Optimised (O3) WA	WASM Emscripten Optimised (Oz) WA
Fibonacci	16.232	36.315	3.550	11.152	10.886
Multiply Doubles	4.533	8.483	4.528	4.648	4.556
Multiply Integers	4.526	6.259	1.724	1.720	1.702
Multiply Double Arrays	663	4550	1.827	2.425	2.477
Prime Numbers	1.486	3382	1.937	3.364	3.317
Bubble Sort	1.326	4.252	0.148	0.145	0.140
QuickSort Double	0.312	1041	0.435	0.170	0.164
QuickSort Int	0.482	1.083	0.361	0.265	0.241
Reverse Array	0.168	0.271	0.029	0.058	0.058
Grayscale	0.061	0.112	0.025	0.033	0.034
Convolution	0.211	0.454	0.231	0.243	0.271
Threshold	0.091	0.197	0.145	0.107	0.056

Chrome Hot - Numerical Computing - Mobile



Chrome Hot - Sorting Image Processing - Mobile



Desktop – Browsers– The Best Results

Algorithms Desktop	JavaScript	WASM	Difference	JavaScript	WASM	Difference	JavaScript	WASM	Difference
	Chrome	Chrome	Chrome	Firefox	Firefox	Firefox	Opera	Opera	Opera
Fibonacci Numbers	18.167	2.809 (API)	15.358	42.855	3.178 (API)	39.677	18.949	2.927 (API)	16.022
Multiply Doubles	2.152	2.039 (API)	113	2.129	2.151 (API)	-22	2.129	2.149 (API)	-20
Multiply Integers	2.056	1.074 Emc(Oz)	982	2.167	1.054 Emc (O3)	1.113	2.171	1.064 Emc (O3)	1.107
Multiply Arrays Double	629	682 (API)	-53	779	693 (API)	86	628	699 (API)	-71
Prime Numbers	5.945	5.925 (API)	20	5.971	5.902 (API)	69	5.954	5.870 (API)	84
Bubble Sort	635	77 Emc (Oz)	558	638	91 (API)	558	634	77 Emc (Oz)	557
Quick Sort Double	205	113 Emc (Oz)	92	261	152 Emc (Oz)	92	207	116 Emc (Oz)	91
Quick Sort	202	100 Emc (Oz)	102	186	149 (API)	102	204	98 Emc (Oz)	106
Reverse Array	630	25 (API)	605	477	26 (API)	605	625	26 (API)	599
Grayscale	40	23 (API)	17	48	18 (API)	30	38	22 (API)	16
Convolution	381	157 (API)	224	416	166 (API)	250	384	158 (API)	226
Threshold	101	51 (API)	50	114	59 (API)	55	101	53 (API)	48

Laptop – Browsers– The Best Results

Algorithms Laptop	JavaScript Chrome	WASM Chrome	Difference Chrome	JavaScript Firefox	WASM Firefox	Difference Firefox	JavaScript Opera	WASM Opera	Difference Opera
	JS	WA		JS	WA		JS	WA	
Fibonacci Numbers	27.159	6.185 (API)	20.974	52.924	4.320 (API)	48.604	32.270	4.154 (API)	28.116
Multiply Doubles	3.931	3.925 (API)	0.006	3.923	3.918 Emc (Oz)	5	3.999	3.929 (API)	70
Multiply Integers	3.939	1.476 (API)	2.463	3.939	1.475 Emc (Oz)	2.464	3.924	1.477 (API)	2.447
Multiply Arrays Double	1.087	1.301 (API)	-214	1.346	1.396 Emc (Oz)	-50	1.058	1.268 (API)	-210
Prime Numbers	6.956	5.024 (API)	1.932	7.662	6.229 (API)	1.433	6.964	5.089 (API)	1.875
BubbleSort	1.038	112 Emc (Oz)	926	2.262	145 Emc (O3)	2.117	1.088	110 (API)	978
QuickSort Double arrays	432	172 Emc (O3)	260	412	255 Emc (Oz)	157	454	156 Emc (O3)	298
QuickSort	416	152 Emc (O3)	264	312	247 Emc (Oz)	65	442	152 Emc (Oz)	290
Reverse Array	1.081	65 (API)	1.016	1.086	64 Emc (Oz)	1.022	1.086	55 Emc (Oz)	1.031
Grayscale	75	62 Emc (O3)	13	76	40 (API)	36	74	45 (API)	29
Convolution	654	292 Emc (O3)	362	719	314 Emc (O3)	405	708	288 (API)	420
Threshold	242	149 Emc (O3)	93	335	161 (API)	174	251	134 (API)	117 ¹⁶

Mobile – Browsers– The Best Results

Algorithms Mobile	JavaScript Chrome	WASM Chrome	Difference Chrome	JavaScript Firefox	WASM Firefox	Difference Firefox	JavaScript Opera	WASM Opera	Difference Opera
	JS	WA		JS	WA		JS	WA	
Fibonacci Numbers	16.232	3.550 (API)	12.682	16.280	3.559 (API)	12.721	16.286	3.532 (API)	12.754
Multiply Doubles	4.533	4.528 (API)	5	4.547	4.535 (API)	12	4.534	4.540 Emc (Oz)	-6
Multiply Integers	4.526	1.702 Emc (Oz)	2.824	4.559	1.703 Emc (Oz)	2.856	4.546	1.700 Emc (Oz)	2.846
Multiply Arrays Double	663	1.827 (API)	-1.164	651	1.914 (API)	-1.263	664	1.820 (API)	-1.156
Prime Numbers	1.486	1.937 (API)	-451	1.463	1.939 (API)	-476	1.467	1.949 (API)	-482
Bubble Sort	1.926	140 Emc (Oz)	1.786	1.930	147 (API)	1.783	1.923	146 Emc (Oz)	1.777
QuickSort Double	312	164 Emc (Oz)	148	444	174 Emc (O3)	270	453	113 Emc (Oz)	340
QuickSort	482	241 Emc (Oz)	241	485	263 Emc (Oz)	222	478	248 Emc (Oz)	230
Reverse Array	168	29 (API)	139	192	57 Emc (Oz)	135	172	24 (API)	148
Grayscale	61	25 (API)	36	51	26 (API)	25	54	26 (API)	28
Convolution	211	231 (API)	-20	235	226 (API)	9	228	237 (API)	-9
Threshold	91	56 Emc (Oz)	35	107	56 Emc (O3)	51	93	55 Emc (Oz)	38

Απόδοση Φυλλομετρητών

Desktop

Browser	Numerical	Sorting	Image Processing
Google Chrome (V8)	2.955	0.163	0.075
Mozilla Firefox (SpiderMonkey)	3.125	0.324	0.104
Opera (Caracan)	2.987	0.167	0.092

Laptop

Browser	Numerical	Sorting	Image Processing
Google Chrome (V8)	4.474	0.239	0.176
Mozilla Firefox (SpiderMonkey)	4.721	0.311	0.194
Opera (Caracan)	4.374	0.250	0.179

Mobile

Browser	Numerical	Sorting	Image Processing
Google Chrome (V8)	3.737	0.242	0.110
Mozilla Firefox (SpiderMonkey)	3.763	0.250	0.111
Opera (Caracan)	3.820	0.243	0.110



Συμπεράσματα

WebAssembly

- Ταχύτητα (ByteCode) - InstantiateStreaming()
- Ασφάλεια (Γραμμική μνήμη - Sandbox)
- Μεγαλύτερη απαίτηση μνήμης
- Πολυπλοκότητα (Garbage collector - DOM)

Μελλοντική Επέκταση

- Enterprise Apps
- Διαχείριση - Κατανάλωση Μνήμης (Browsers)
- Διαφορετικές Γλώσσες Προγραμματισμού (C++, Rust, TypeScript)
- Παραλληλισμός

- ANY QUESTIONS?

Thank you!