



Parallel.es

Parallelize your JavaScript Applications with Ease

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HSR

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Parallel.es

Overview

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Motivation

Motivation for Parallelization

- Performance

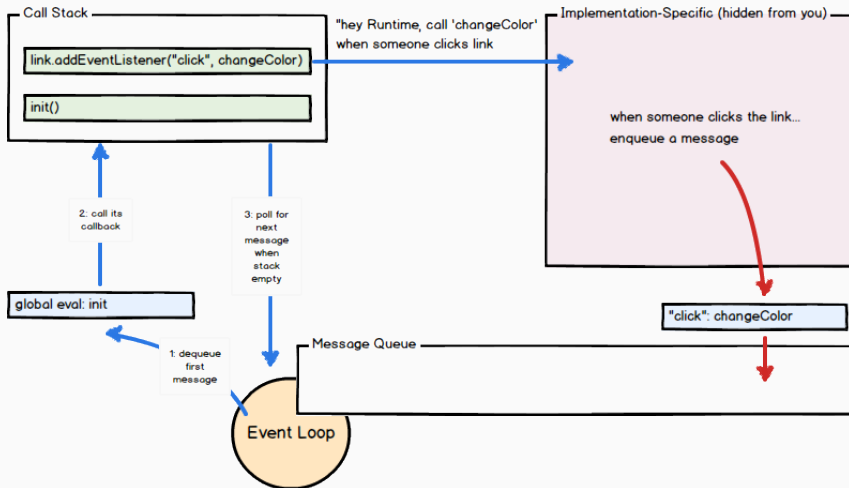
Motivation for Parallelization

- Performance
- ...but moreover, a better user experience

A better User Experience?

- Because JavaScript is single threaded
- Long running tasks are blocking the UI-thread
- and therefore, the UI is not responsive

The JavaScript Event Loop is the Reason therefore



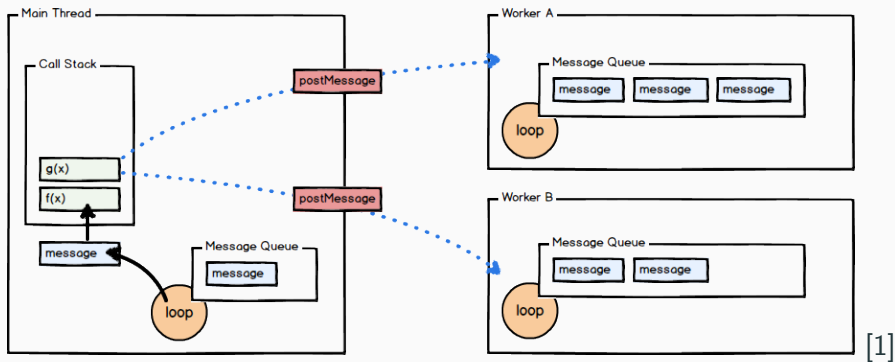
[1]

Initial Position

Technologies offered by the Runtime Environment

- Browser: Web Worker Standard [2]
- Node: Child Process [3]
- JVM: RingoJS [4]

Web Worker Architecture



Memory

Each Web Worker uses a distinct runtime environment (e.g. V8), therefore, the memory of each web worker is distinct too.

“Simple” Web Worker Example

main.js

```
1  const worker = new Worker("./worker.js");
2  worker.postMessage(40);
3
4  worker.addEventListener(
5    "message",
6    result => console.log(result.data)
7  );
```

“Simple” Web Worker Example

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4  worker.addEventListener(
5    "message",
6    result => console.log(result.data)
7  );
```

worker.js

```
1  function fib(num) {
2    if(num <= 2) {
3      return 1;
4    }
5    return fib(num - 1) + fib(num - 2);
6  }
7
8  onmessage = function (event) {
9    const num = event.data;
10   const result = fib(num);
11   postMessage({
12     number: num,
13     fib: result
14   });
15  };
```

But I also have to...

- Handle Errors
- Return a Promise in the UI-Thread
- Perform the Computation for multiple Items
- Besides, it should run on Node.JS too

And I don't like that...

- code splitting is enforced by technology instead of by semantics
- the messaging model results in a clear seam
- integration adds non inherent complexity
- the build gets far more complicated

Parallel.es

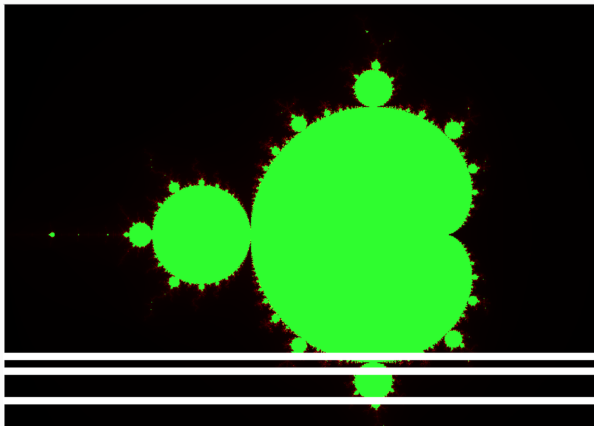
Parallel.es eases parallelizing JavaScript applications

- The API is type-safe
- ...and runtime environment independent, write once, run everywhere
- Uses a thread pool
- Detects the optimum of threads to create

“Simple” Example

```
1  import parallel from "parallel-es";
2
3  function fib(num) {
4    if(num <= 2) {
5      return 1;
6    }
7    return fib(num - 1) + fib(num - 2);
8  }
9
10 parallel.run(fib, 40)
11   .catch(error => console.error(error))
12   .then(result => console.log(result));
```

The Mandelbrot Showcase



<https://michareiser.github.io/parallel-es-example/>

Code for Single Threaded Execution

```
1  const imageWidth = 10000;
2  const imageHeight = 10000;
3
4  function computePixel(x, y) {
5      // ...
6      return n;
7  }
8
9  function computeMandelbrotLine(y) {
10     const line = new Uint8ClampedArray(imageWidth * 4);
11     for (let x = 0; x < imageWidth; ++x) {
12         line[x * 4] = computePixel(x, y);
13     }
14     return line;
15 }
16
17 const result = _.chain()
18     .range(imageHeight)
19     .map(computeMandelbrotLine)
20     .value();
```

- Compute Lines in Background Threads
- Preferred, create as many Background Threads as CPU's are available

Poor Mans Solution

```
1  const imageWidth = 10000;
2  const imageHeight = 10000;
3
4  function computePixel(x, y) {
5    // ...
6    return n;
7  }
8
9  function computeMandelbrotLine(y) {
10   // ...
11   return line;
12 }
13
14 for (int i = 0; i < imageHeight; ++i) {
15   parallel.run(computeMandelbrotLine, i).then(line => {
16     // draw to canvas
17   });
18 }
```

It works¹! But...

- I don't want to be responsible to split the work on multiple threads
- Flow of logic is hard to catch

¹Actually, it depends, details follow

Therefore, Parallel.es offers a descriptive API

- Inspired by lodash / underscore
- Handles Work Partitioning
- Allows subscribing to sub results
- ...or the joined overall result

Descriptive Implementation

```
1  const imageWidth = 10000;
2  const imageHeight = 10000;
3
4  function computePixel(x, y) {
5    // ...
6    return n;
7  }
8
9  function computeMandelbrotLine(y) {
10   const line = new Uint8ClampedArray(imageWidth * 4);
11   for (let x = 0; x < imageWidth; ++x) {
12     line[x * 4] = computePixel(x, y);
13   }
14   return line;
15 }
16
17 parallel
18   .range(imageHeight)
19   .map(computeMandelbrotLine)
20   .subscribe((subResult, index, batchSize) => /* draw line */)
21   .catch(error => /* handle error in computation of any line */)
22   .then(result => /* handle overall result */);
```


Each Worker has its distinct memory and therefore,

- data needs to be transferred between workers
- ... as well as all functions executed in background threads

Comparsion to other Languages

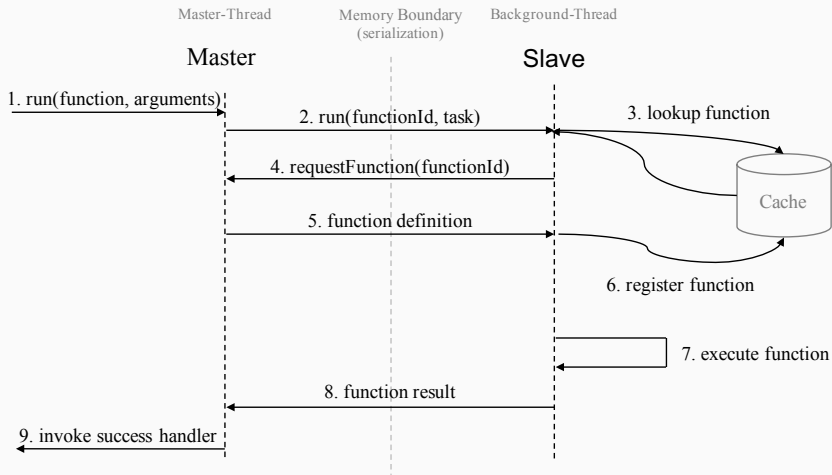
Other languages, e.g. Java, have a shared memory that is accessible by all threads.

However, parallelization in JavaScript is more like multiprocess programming using inter process communication.

Two Possibilities

- Runtime Serialization of Functions
- Transpilation of Source Code

Runtime Serialization of Functions - Overview



Runtime Serialization of Functions - Serialization

```
1  const s = func.toString();
2  const name = getFunctionName(func);
3  const args = s.substring(s.indexOf("(") + 1, s.indexOf(")")).split(",");
4  const body = s.substring(s.indexOf("{") + 1, s.lastIndexOf("}")).trim();
5
6  const definition = {
7    argumentNames: args.map(arg => arg.trim()),
8    body,
9    id,
10   name: name ? name : undefined
11  };
```

Runtime Serialization of Functions - Deserialization

```
1  if (definition.name) {
2    const args = definition.argumentNames.join(", ");
3    const source = `return function ${definition.name} (${args}) {
4      ${definition.body}
5    };`;
6    const wrapper = Function.apply(undefined, [ source ]);
7    return wrapper();
8  }
9
10 return Function.apply(undefined, [
11   ...definition.argumentNames,
12   definition.body
13 ]);
```

But what about a Function's Closure?

- Transitive Functions
- ...or Variables referenced from the Function's outer Scope

are not supported by Runtime Serialization

Why Not?

It's possible to analyze a function at runtime, e.g. by using Babel. However, there is no way to get access to the values of a function's closure as it is the case in C#.

The Issue with Function Closures and Runtime Serialization

UI-Thread

```
1  const width = 10000;
2  const height = 10000;
3
4  function computePixel(x, y) {
5    // ...
6  }
7
8  function computeMandelbrotLine(y) {
9    const l = new Uint8ClampedArray(width * 4);
10    for (let x = 0; x < width; ++x) {
11      l[x * 4] = computePixel(x, y);
12    }
13    return l;
14  }
15
16  parallel
17    .range(height)
18    .map(computeMandelbrotLine)
19    .then(result => /* handle overall result */);
```

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```

Worker-Thread

```
1  function computeMandelbrotLine(y) {
2    const l = new Uint8ClampedArray(width * 4);
3    for (let x = 0; x < width; ++x) {
4      l[x * 4] = computePixel(x, y);
5    }
6    return l;
7  }
```

Issue

height variable and computePixel function are not defined in worker-thread.

- Analyses all calls to `parallel`
- Extracts passed functions
- ...and as well transitive functions
- Registers these functions in the background-thread source file
- Split into a Babel (extraction) and Webpack-Plugin (registration)

Transpiled Code of Mandelbrot Example

UI-Thread

```
1  const width = 10000;
2  const height = 10000;
3
4  function computePixel(x, y) {
5    // ...
6  }
7
8  function _environmentExtractor() {
9    return { width: width };
10 }
11
12 function computeMandelbrotLine(y) {
13   const l = new Uint8ClampedArray(width * 4);
14   // ...
15   return l;
16 }
17
18 parallel
19   .range(height)
20   .inEnvironment(_environmentExtractor())
21   .map({
22     identifier: "static:_entrycomputeMandelbrotLine",
23     _____isFunctionId: true
24   })
25   .then(result => console.log(result));
```

Worker-Thread

```
1  var width;
2  function computePixel(x, y) {
3    // ...
4  }
5
6  function computeMandelbrotLine(y) {
7    var l = new Uint8ClampedArray(width * 4);
8    // ..
9    return l;
10 }
11
12 function _entrycomputeMandelbrotLine() {
13   try {
14     var _environment = arguments[arguments.length - 1];
15     width = _environment.width;
16     return computeMandelbrotLine.apply(this, arguments);
17   } finally {
18     width = undefined;
19   }
20 }
21
22 slaveFunctionLookupTable.registerStaticFunction({
23   identifier: 'static:_entrycomputeMandelbrotLine',
24   _____isFunctionId: true
25 }, _entrycomputeMandelbrotLine);
```

Use Case

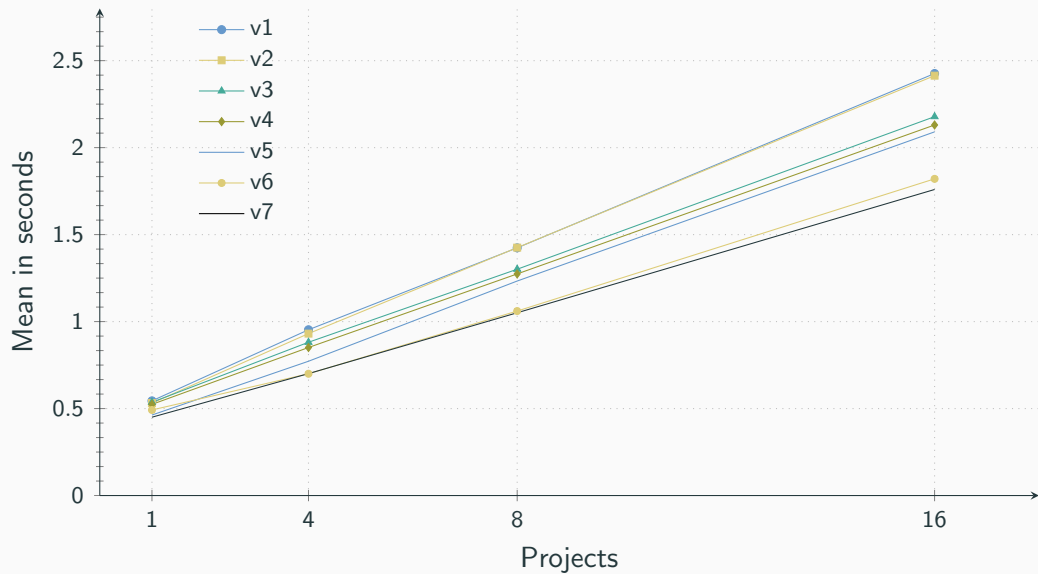
Riskprofiling



Performance Improving prior Parallelization

- A problem needs to be parallelizable
- Parallelization always adds complexity
- Maybe it's enough to improve “synchronous” code

Execution Time for 100'000 runs



- Computes the simulation result over 15 years
- For each project
 - Creates the four groups “red, gray, yellow, green”
 - Creates for each group 10 buckets and assigns the simulation values
- Median, min, max are computed in the chart

Main Concern

Simulation returns all values instead of the needed information median, min and max. Therefore, absolutely unsuited for parallelization because of large data amount to be transferred.

V2, only returns Information needed by Chart

- Marginal Faster (no array resizes, $\approx 20\text{ms}$)
- Chart needs to perform less computations
- Easier to parallelize, less data needs to be transferred

V3, Address V8 deoptimizations

If you see this...

▼ ⚠ (anonymous)	<u>benchmark.js:319:</u>
▶ calculateProject	<u>benchmark.js:12:</u>
▶ ⚠ (anonymous)	<u>benchmark.js:12:</u>
▶ ⚠ (anonymous)	<u>benchmark.js:228:</u>

... you are doomed ;)

...or at least, there is much Room for Improvements

V8 Optimization Killers [5]

- Unsupported Syntax (e.g. `debugger`, `eval`, `with`, generator functions...)
- Manipulating arguments
- Very large Switch-case Statements (+128 cases)
- `for in`
- Infinite Loops with deep logic or unclear exit
- Others

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- Others

Workaround

- Clean Code
- Small Functions

In this Case, the Reason is a Dynamic Object Structure

```
1  const valuesByGroup: { [groupName: string]: number } = {};  
2  const bucketSize = Math.round(simulatedValuesThisYear.length / NUMBER_OF_BUCKETS);  
3  const buckets: IBucket[] = [];  
4  
5  for (let i = 0; i < simulatedValuesThisYear.length; i += bucketSize) {  
6      const bucket: IBucket = {  
7          max: Number.MIN_VALUE,  
8          min: Number.MAX_VALUE,  
9          subBuckets: {}  
10     };  
11  
12     for (let j = i; j < i + bucketSize; ++j) {  
13         const value = simulatedValuesThisYear[j];  
14         bucket.min = Math.min(bucket.min, value);  
15         bucket.max = Math.max(bucket.max, value);  
16  
17         const group = groupForValue(simulatedValuesThisYear[j], groups);  
18         valuesByGroup[group.name] = (valuesByGroup[group.name] || 0) + 1;  
19         const subBucket = bucket.subBuckets[group.name] = bucket.subBuckets[group.name] ||  
20             { group: group.name, max: Number.MIN_VALUE, min: Number.MAX_VALUE };  
21         subBucket.min = Math.min(subBucket.min, value);  
22         subBucket.max = Math.max(subBucket.max, value);  
23     }  
24  
25     buckets.push(bucket);  
26 }
```

...that makes it Impossible to Optimize the Property Access

valuesByGroup	valuesByGroup	valuesByGroup	valuesByGroup
green	yellow	yellow	red
yellow	green	green	gray
gray	gray	gray	green
red	red		yellow

Depending on the order of the simulated values the offset for the properties differ, e.g. for “green”:

1. +0

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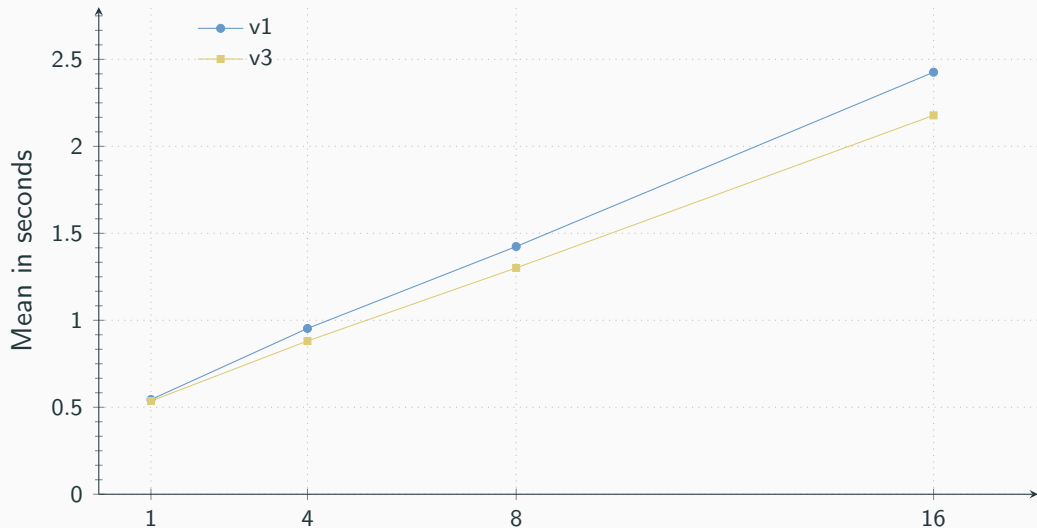
Therefore, V8 deoptimizes the **whole** function

Solution: Ensure that the Object is always Initialized in the same Order

```
1  const bucket: IBucket = {
2    max: Number.MIN_SAFE_INTEGER,
3    min: Number.MAX_SAFE_INTEGER,
4    // Needed to avoid deoptimization because of changed attribute orders in subBuckets. Initialize with const order
5    subBuckets: {
6      green: {
7        group: "green",
8        max: Number.MIN_SAFE_INTEGER,
9        min: Number.MAX_SAFE_INTEGER,
10       empty: true
11     },
12     yellow: {
13       group: "yellow",
14       max: Number.MIN_SAFE_INTEGER,
15       min: Number.MAX_SAFE_INTEGER,
16       empty: true
17     },
18     //...
19   }
20 };
```

This small Change Improves Performance by up to 235ms

Execution Time for 100'000 runs



Further Improvements

- v4: Reduce Nesting of Functions (-47ms)
- v5: Create Arrays with expected Size (-60ms)
- v6: Only simulate number of Years needed (-270ms)
- v7: Avoid Object Destructuring (-61ms)

Overall

Improvement by 666ms in best case (1.76 instead of 2.426s) or by 28%

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- So it only makes sense to parallelize if there are 2+ projects

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But Performance is not everything

The UI is no longer blocked for $\approx 2s$

Performance Improvement of up to 300ms (2 Cores, HT)



But sometimes it is even slower.

Conclusion

Conclusion

- Parallel.es eases writing multithreaded JS applications
- It is platform independent
- Compared to alternatives ([6]–[8]),
 - The API is type-safe
 - Performs well in most cases
 - Transpilation allows a seamless integration
- Source Map support is helpful
- However, no support for
 - Low Level synchronization primitives
 - Recursive Tasks

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- ... maybe, these improvements are already sufficient
- ... and parallelization always adds non-inherent complexity

Further Work

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- Provides a stack machine
- Allows to run C++ code in the browser
- However, who wants to write C++ ;)
- Controversial Idea: compile a subset of JS to Web Assembly
- Hopefully profit from better performance
- And if time allows, take benefit of the pthreads API






Further Resources


- Project Page [9]
- Project Thesis Paper [10]
- Optimization Killers [5]

References I

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Questions and Discussion