

Optimizing Links for performance hungry applications

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version 3
[final]

Gist

This document describes various minor optimizations to Links JavaScript runtime (*jslib.js*) and their effectiveness. The overall performance of Links is assessed and possible optimizations are proposed and discussed.

Observations

There's a lot of room for improvement. Simple optimizations increased performance significantly.

Problem

Garbage collector slowdowns.

Cause

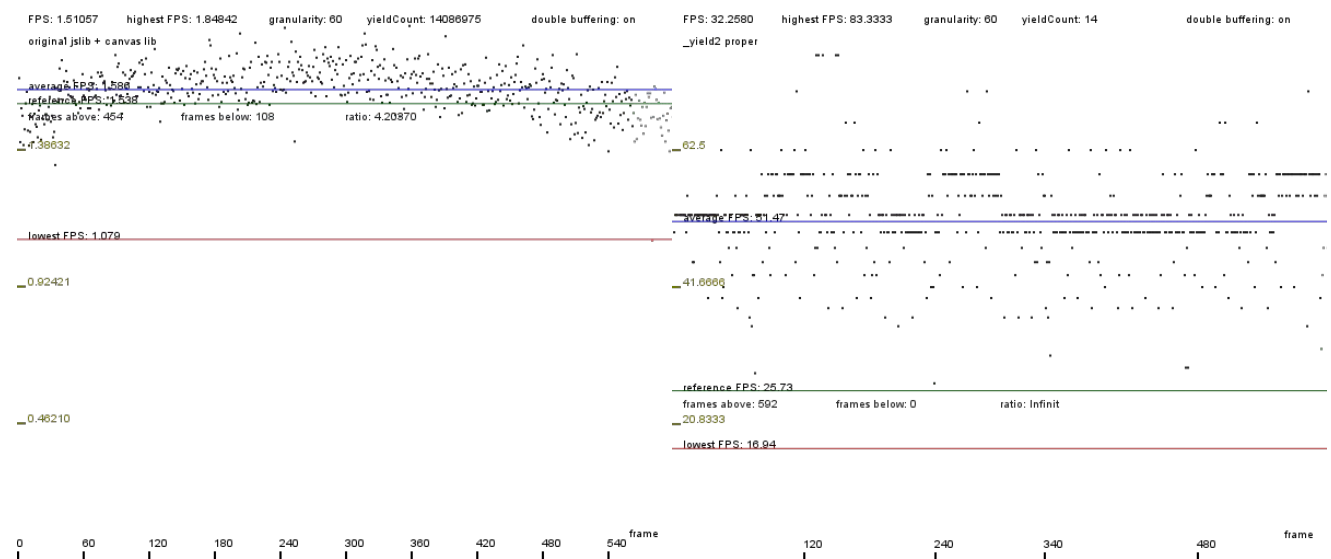
Periodical collection of large amounts of garbage by the browser's garbage collector.

Proposed solutions

- Write applications in a way that avoids generating garbage. For Links it means enabling (more) ways to do it as well as optimizing the compiler and the runtime, so that less garbage is being generated.
- Optimize some Links' data structures and functions.
- Optimize JavaScript generated by the compiler.
- Implement a custom garbage collector/give the user more control over memory.
- Make the compiler generate code for a language that compiles to LLVM bytecode, then generate fast JavaScript from it using Emscripten¹ (or something similar). This would most likely also mean implementing a custom garbage collector.

¹ <http://en.wikipedia.org/wiki/Emscripten>

The following charts illustrate the effectiveness of the optimizations as well as the problem described above:



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Introduction

This section describes how the performance measurements were carried out.

I tried to make sure that the measurements are done properly. Considering the short time in which all this was done, I might have missed something (most likely did), but nonetheless acquired data shows interesting things. The following paragraphs describe how the data was obtained.

The benchmark application

I wrote an application (see the file *performance-frozen.links* – attached to this document) in Links, which displays a chart of instantaneous FPS² for every frame (numbers of frames are on the X axis and the instantaneous FPS is on the Y axis).

The application is itself very resource consuming, though all it does is processing 600 samples of FPS data and drawing on the screen. I didn't make attempts at optimizing it, though, because that's irrelevant – it's enough that the same application is used unchanged for every measurement.

Links' debug mode was off during all tests (`debug=off` in the config file). I made sure not to have any extra applications running in the background while testing (aside from a text editor, file manager and a terminal emulator, which were running constantly). All tests were performed using Chromium 36.0.1985.143 on Arch Linux on an ASUS X53S laptop.

I generated over 100 charts. For this document I selected a representative chart for each optimization.

The next section describes all relevant files that were used during measurements: the benchmark application as well as the runtime. Different versions of the runtime were produced by modifying the original. This allowed me to easily test different optimizations in isolation as well as in combination.

2 http://en.wikipedia.org/wiki/Frame_rate. *Instantaneous* means that it indicates how many frames could be processed in a second, if all frames in that second took as much time to process as the current frame.
Note: I'm using the word *framerate* and *FPS* interchangeably throughout this document.

Files attached to this document

Various versions of the benchmark application are attached to this document as the following files:

- **performance-frozen.links** – the original benchmark application in Links (most charts in this document were generated by it)
- **performance-frozen-optimized.html** – a version of the original benchmark optimized by the Google Closure Compiler³
- **performance.html** – native JavaScript version of the benchmark application
- **performance2.links** – a working/improved version of *performance-frozen.links*. Not up to date [[REMOVE]]
- **BASE performance-frozen-lists.links** – performance-frozen.links with a custom list type defined in Links. This is the base for all files named **performance-frozen-lists*.
- **TAKE-DROP performance-frozen-lists.links** – uses JavaScript versions `lsTake` and `lsDrop` (which work like `take` and `drop`) defined in *JS lists 2 - map jslib.js*
- **JS LISTS 2 - MAP performance-frozen-lists.links** – uses a custom JavaScript linked list type (defined in *JS lists 3 - map jslib.js*)
- **JS LISTS 3 - MAP performance-frozen-lists.links** – uses a custom optimized JavaScript linked list type (defined in *JS lists with null - map jslib.js*)
- **specialized equality performance-frozen-lists.links** – uses specialized functions for testing equality (defined in *specialized equality jslib.js*)

Other files attached to this document:

- **lib.ml** – the original *lib.ml* + interface for canvas manipulation
- **lib 2.ml** – the above *lib.ml* + interface for manipulating linked lists and specialized equality functions
- **irtojs.ml** – the original *irtojs.ml* adjusted for an optimized version of `_yield`

³ <https://developers.google.com/closure/compiler/>

Various versions of the Links runtime (*jslib.js*)⁴:

- **original jslib + canvas lib.js** – the original (unoptimized) version of *jslib.js* which was used as a reference – I added only the interface for canvas manipulating functions to it. I used the *jslib.js* file from GitHub – from the version of *sessions* branch (last commit July 30), which my branch (*dariusz*⁵) was derived from.
- **optimized _yield and _yieldCont jslib.js** – the original with optimized versions of *_yield* and *_yieldCont* functions – the optimization removed any references to functions in the *DEBUG* namespace from the body of *_yield* and *_yieldCont* and made some other minor changes
- **setZeroTimeout jslib.js** – the original with all calls to *setTimeout* with the second argument of 0 replaced by a call to *setZeroTimeout*⁶
- **_yieldGranularity + 200 jslib.js** – the original with *_yieldGranularity* increased from 60 to 260
- **new base jslib.js** – the original with optimizations from *optimized _yield and _yieldCont jslib.js* and *setZeroTimeout jslib.js* combined
- **optimized yield + setZeroTimeout jslib.js** – same as previous
- **new base + _yieldGranularity + 200 jslib.js** – *new base jslib.js* with *_yieldGranularity* increased from 60 to 260
- **google closure jslib.js** – modified *new base jslib.js* with a function for invoking Chromium debugger; this file was used as part of the input to Google Closure Compiler; the whole input is attached in the file **google closure input.js**
- **JS lists 2 - map jslib.js** – adds a few functions for manipulating a linked list type defined in *JS LISTS 2 - MAP performance-frozen-lists.links*
- **JS lists 3 - map jslib.js** – defines a linked list type (based on the one in the Elm language⁷) and functions for manipulating it entirely in JavaScript. Used with *JS LISTS 3 - MAP performance-frozen-lists.links*
- **JS lists with null - map jslib.js** – *JS lists 3 - map jslib.js* with further optimizations of the linked list type
- **specialized equality jslib.js** – adds specialized JavaScript functions for testing for equality as (theoretically faster) an alternative to *LINKS.eq*
- **proper yield2 jslib.js** – adds an optimized version of *_yield* that required a slight change in the JavaScript generated by the compiler (*irtojs.ml* was adjusted for this optimization – it is attached to this document)

4 The names of the attached files approximately correspond to descriptions (if present) found on charts

5 <https://github.com/slindley/links/compare/dariusz>

6 Implementation from <http://dbaron.org/log/20100309-faster-timeouts>

7 <http://elm-lang.org/elm-runtime.js>

Basic optimizations

This section contains the generated charts with descriptions.

The chart-generating application works like this: every frame the highest and the lowest FPS is updated if needed. Every 600 frames (an *iteration*) the average FPS is calculated and collecting samples starts over. The samples from the previous iteration are marked with gray and the samples from the current iteration are marked with black.

Every chart consists of:

- **X axis** (frames): from 0 to 600, a mark every 60 frames
- **Y axis** (instantaneous FPS): from 0 to the highest registered FPS, marks at 25, 50 and 75% of the highest FPS
- **Blue line** – indicating the average FPS (calculated over 600 frames from the previous iteration)
- **Green line** – user-defined reference FPS. Can be moved with up and down arrow keys. Below this line are three values dependent on its position:
 - Frames above – how many samples calculated in this iteration lie above the reference line
 - Frames below – how many samples lie below the line
 - Ratio – the number of frames above the line divided by the number of frames below
- **Red line** – indicates the lowest instantaneous FPS
- Text at the top:
 - FPS – current instantaneous FPS
 - highest FPS – highest instantaneous FPS
 - granularity – the value of `_yieldGranularity` (constant)
 - yieldCount – current value of `_yieldCount`; in the charts without the first optimization this value is very high as it is incremented every time `_yield` or `_yieldCont` is called (eventually it overflows, which may cause an unplanned stack clear); after the optimization the value is reset when it reaches the value of `_yieldGranularity`
 - double buffering – indicates whether double buffering⁸ is on or off⁹
 - description – the second line from the top describes the chart⁷

8 http://en.wikipedia.org/wiki/Multiple_buffering#Double_buffering_in_computer_graphics

9 See the last section of this document for details

The problem

There's a clear pattern in the optimized versions: every n frames the FPS drops significantly – this is caused by the garbage collector collecting large amounts of garbage periodically¹⁰. The green line on every chart may be helpful in estimating the n .

The unoptimized version

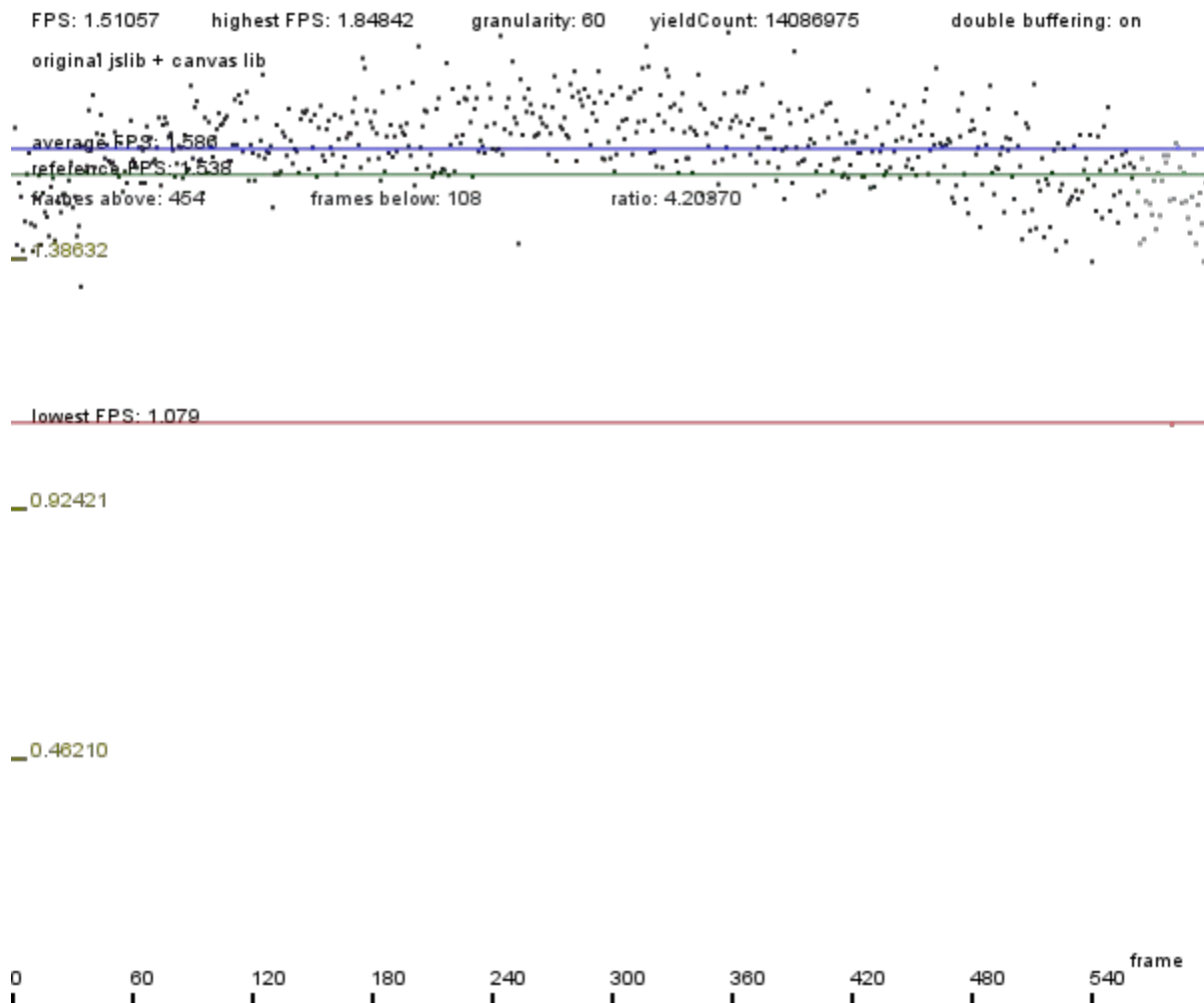


Chart 3: The unoptimized version

Average FPS ~ 1.6. This is the reference.

¹⁰ See the section: Garbage collector's behavior.

First optimization – optimized `_yield` and `_yieldCont`

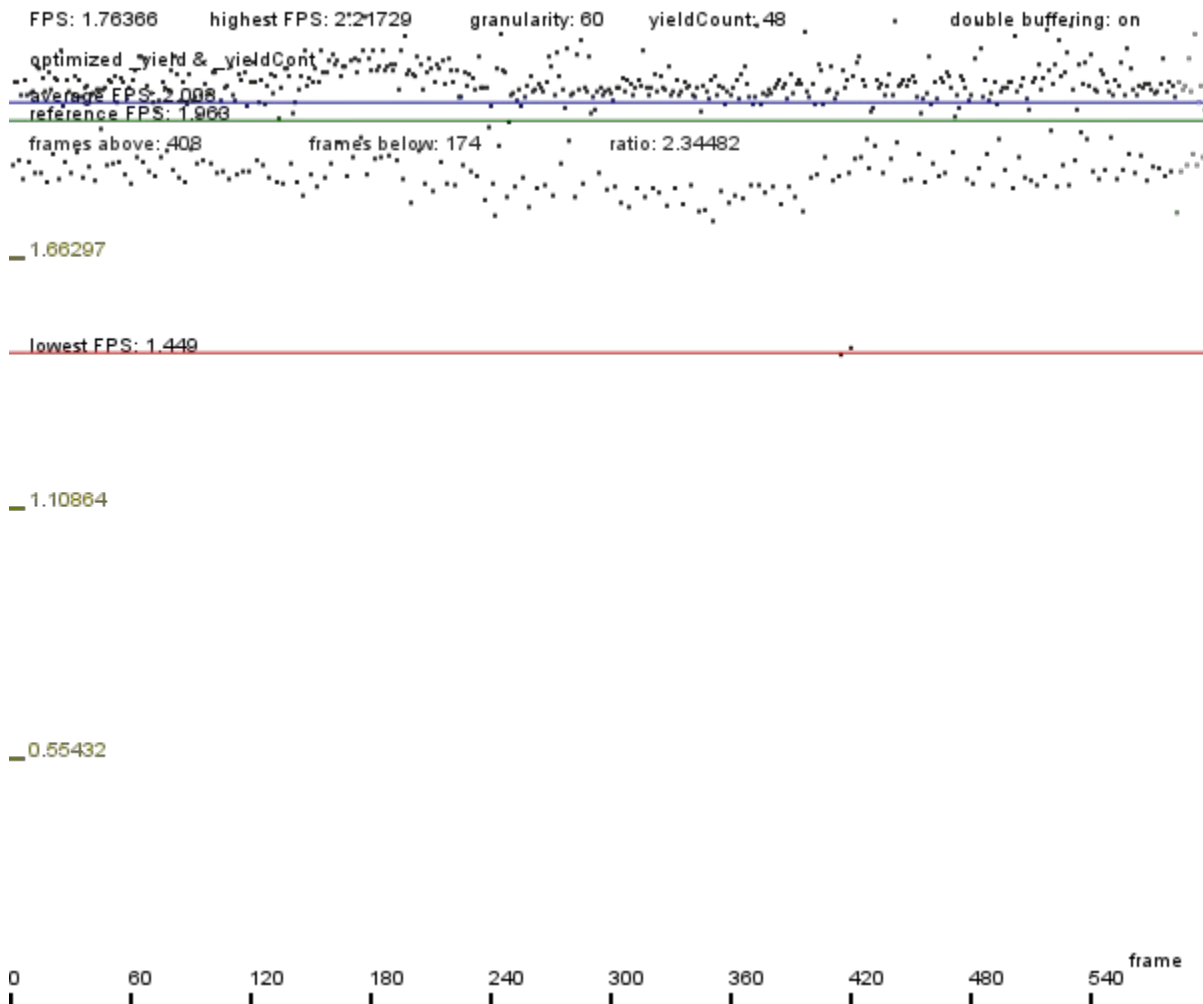


Chart 4: First optimization – faster `_yield`*

Average FPS ~ 2.

Removing some calls to debugging functions from the bodies of `_yield` and `_yieldCont` and getting rid of one modulo operation and one negation improved the performance a bit. In fact the improvement is much more significant than what comparing this chart to the previous may indicate, as we'll see when we combine this optimization with the next one.

We can see the pattern described in The problem: the framerate oscillates between some higher and lower value. It drops almost every third frame.

Second optimization – faster setTimeout

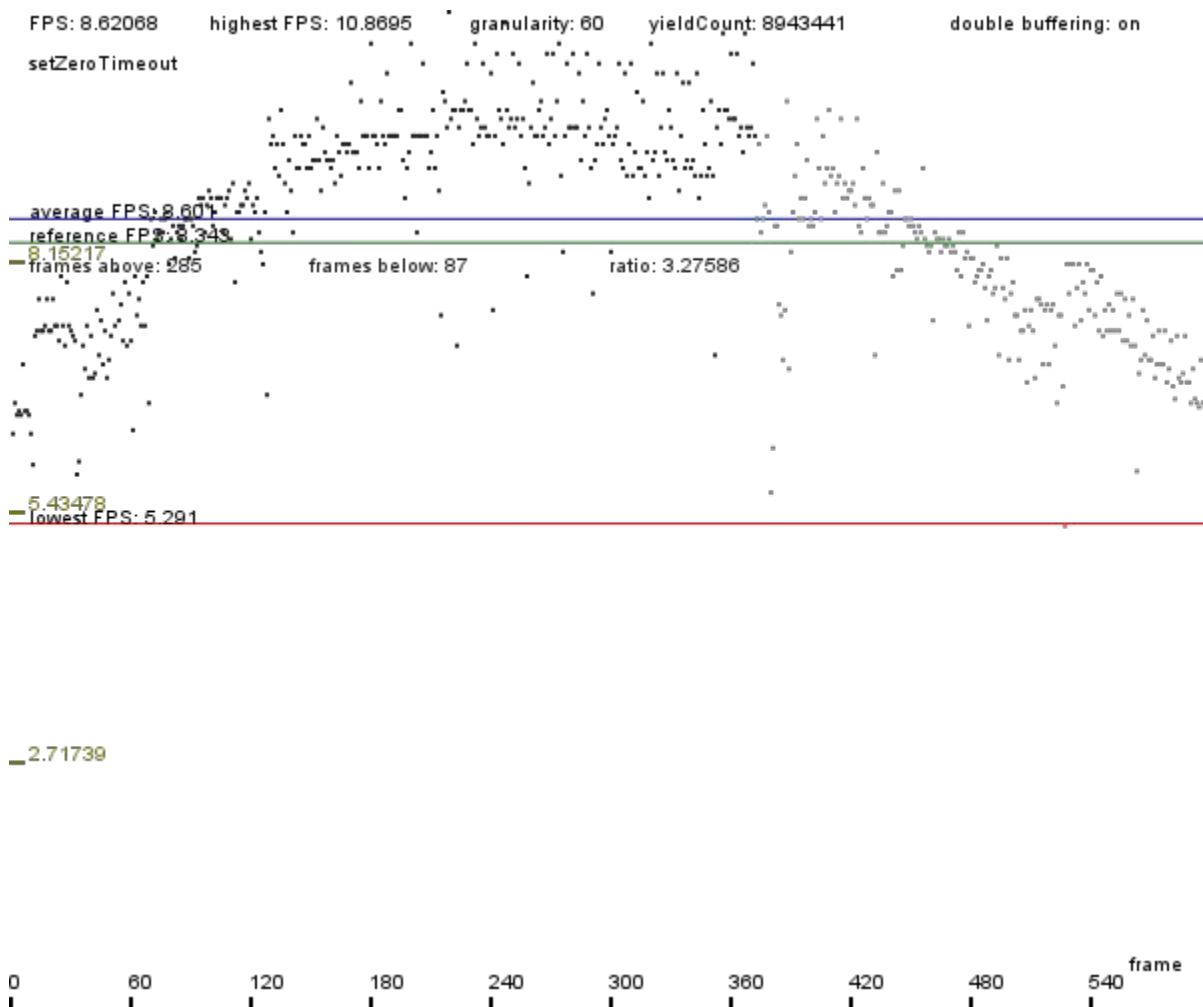


Chart 5: Second optimization – `setZeroTimeout`

Average FPS ~ 8.6.

All calls to `setTimeout` with the second argument of 0 were replaced by a call to `setZeroTimeout`¹¹ – a major optimization. `setTimeout` effectively has a minimum delay of about 4 ms¹¹. `setZeroTimeout` doesn't have that limitation.

The oscillation of the FPS is more apparent when the `_yield*` optimization is applied – so not here. This is most likely because the amount of time spent yielding each frame is much longer without the optimization and garbage collecting time stays roughly the same.

¹¹ https://developer.mozilla.org/en/docs/Web/API/window.setTimeout#Minimum.2F_maximum_delay_and_timeout_nesting

Third optimization – increasing `_yieldGranularity`

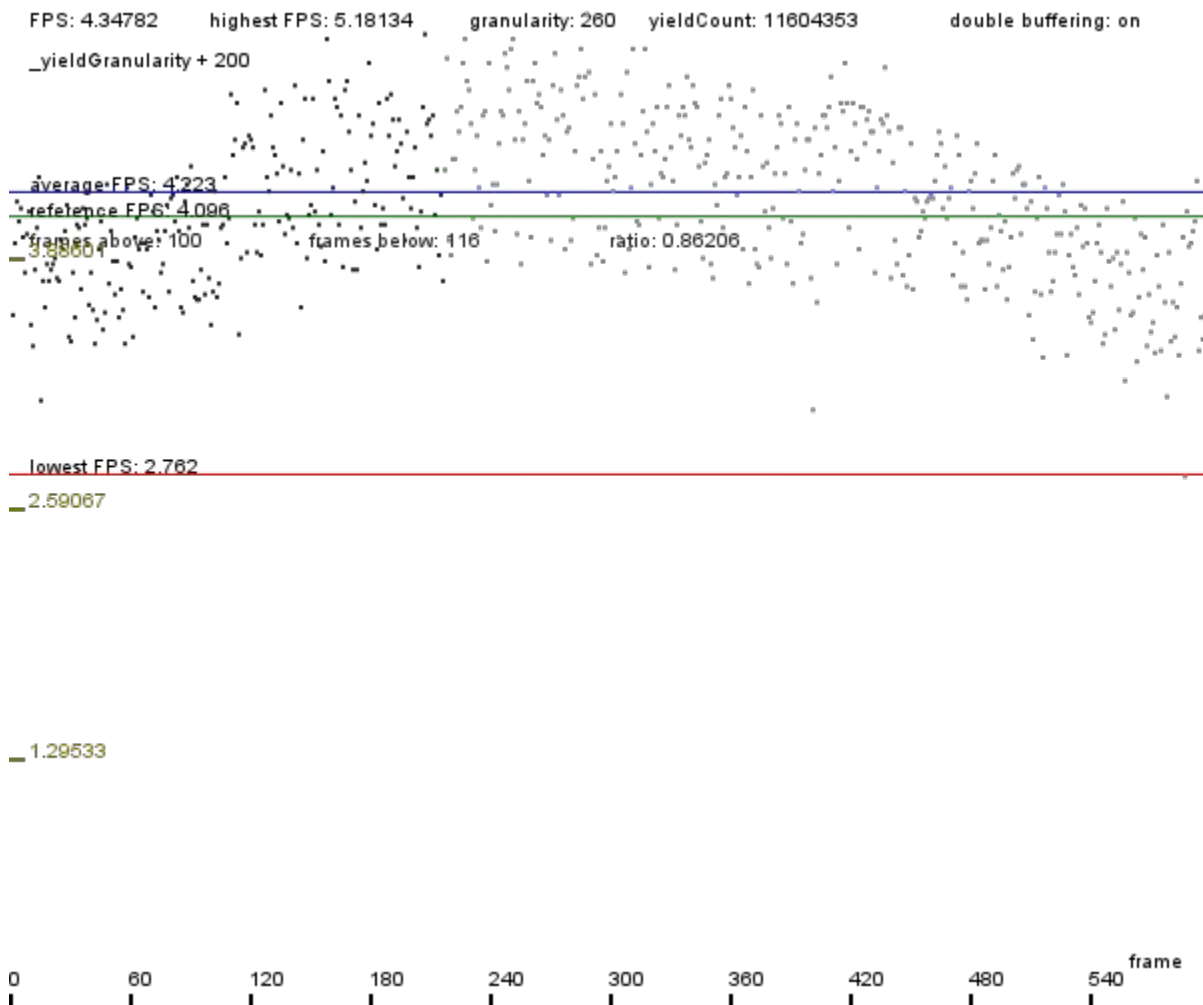


Chart 6: Third optimization – calling `setTimeout` less often

Average FPS ~ 4.2.

Increasing `_yieldGranularity` obviously has an impact on performance, as stack is not cleared so often (but this works up to a point¹² and the maximum value of `_yieldGranularity` differs between applications and browsers).

¹² Because as `_yieldGranularity` grows the amount of garbage being accumulated also grows (see Chart 12)

Fourth optimization – turning off double buffering¹³

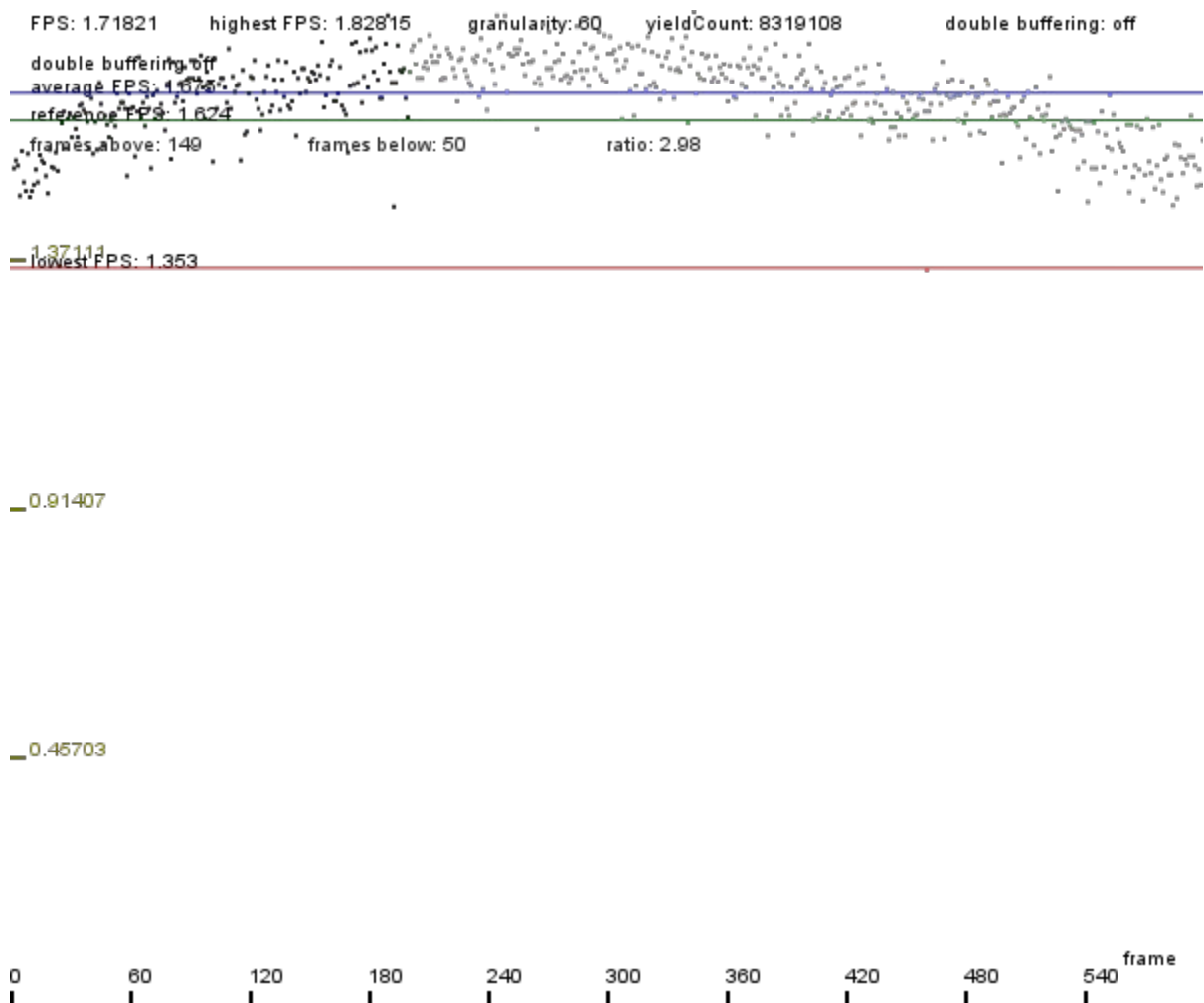


Chart 7: Fourth optimization – double buffering off

Average FPS ~ 1.7.

Almost no effect compared to the original. That's most probably because drawing is one of the least performance significant parts of the benchmark application. Doing similar tests with a Breakout clone in Links shows that turning off double buffering has, as expected, a significant effect.

¹³ Normally browsers do double buffering automatically (<http://www.mail-archive.com/whatwg@lists.whatwg.org/msg19969.html>), but it won't work for Links, most likely because the generated JavaScript for the drawing makes asynchronous calls all the time, so currently to avoid flickering of the canvas double buffering has to be always on.

First two optimizations combined

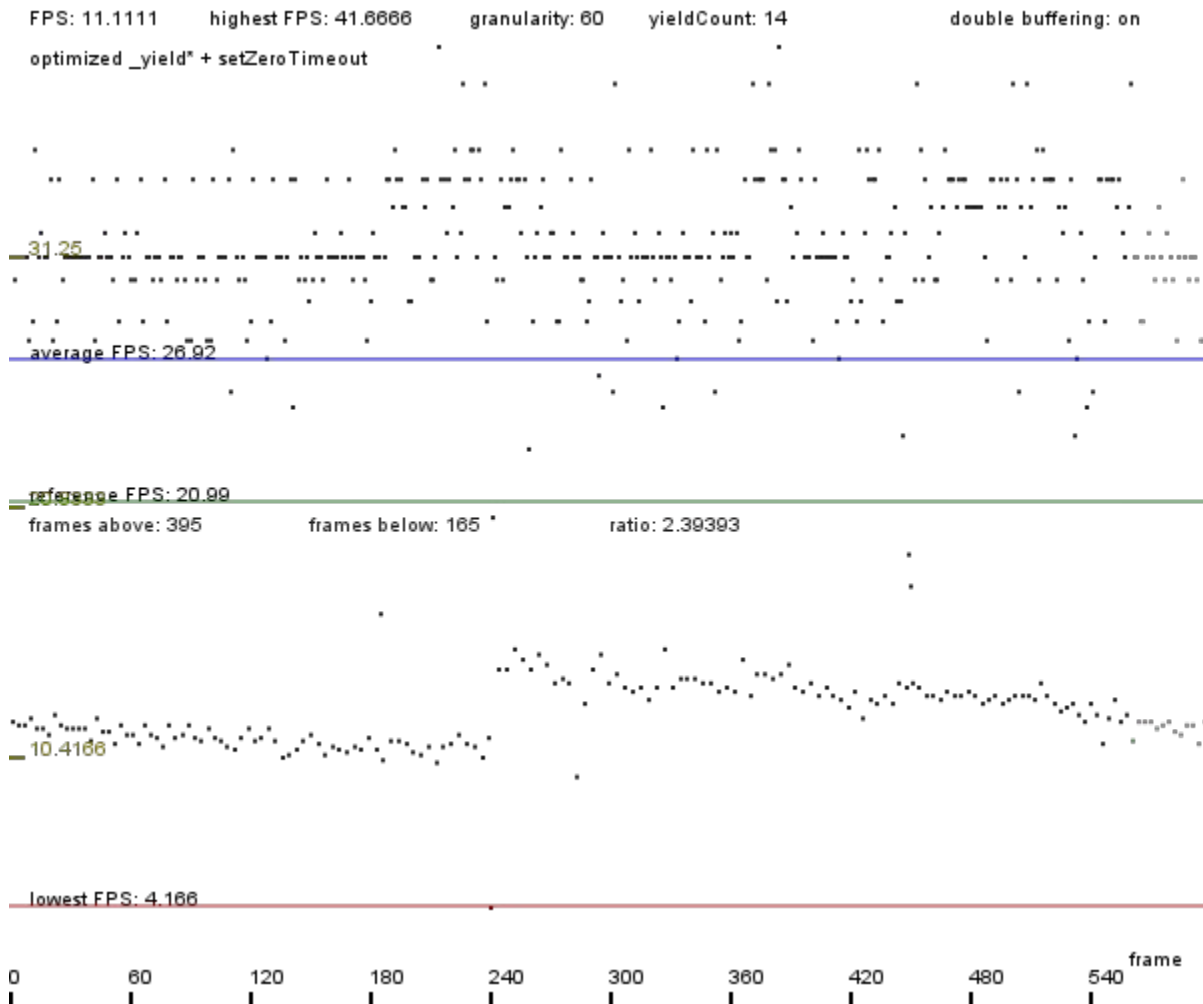


Chart 8: First two optimizations combined

Average FPS ~ 27.

Great improvement. The oscillation clearly apparent.

First three optimizations combined

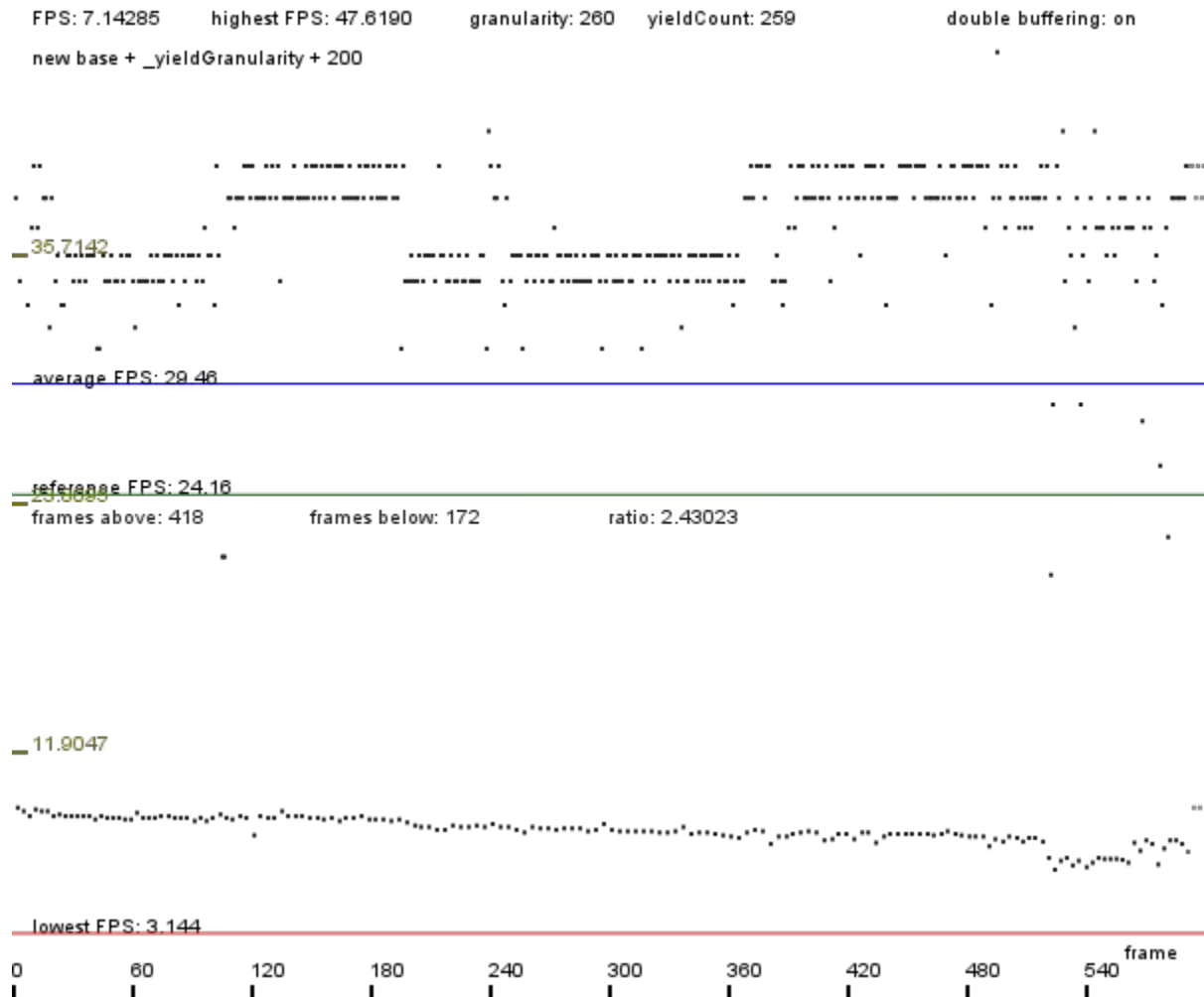


Chart 9: First three optimizations combined

Average FPS ~ 29.

An increase in `_yieldGranularity` bumps up the FPS a bit, but not that significantly.

First two optimizations without double buffering

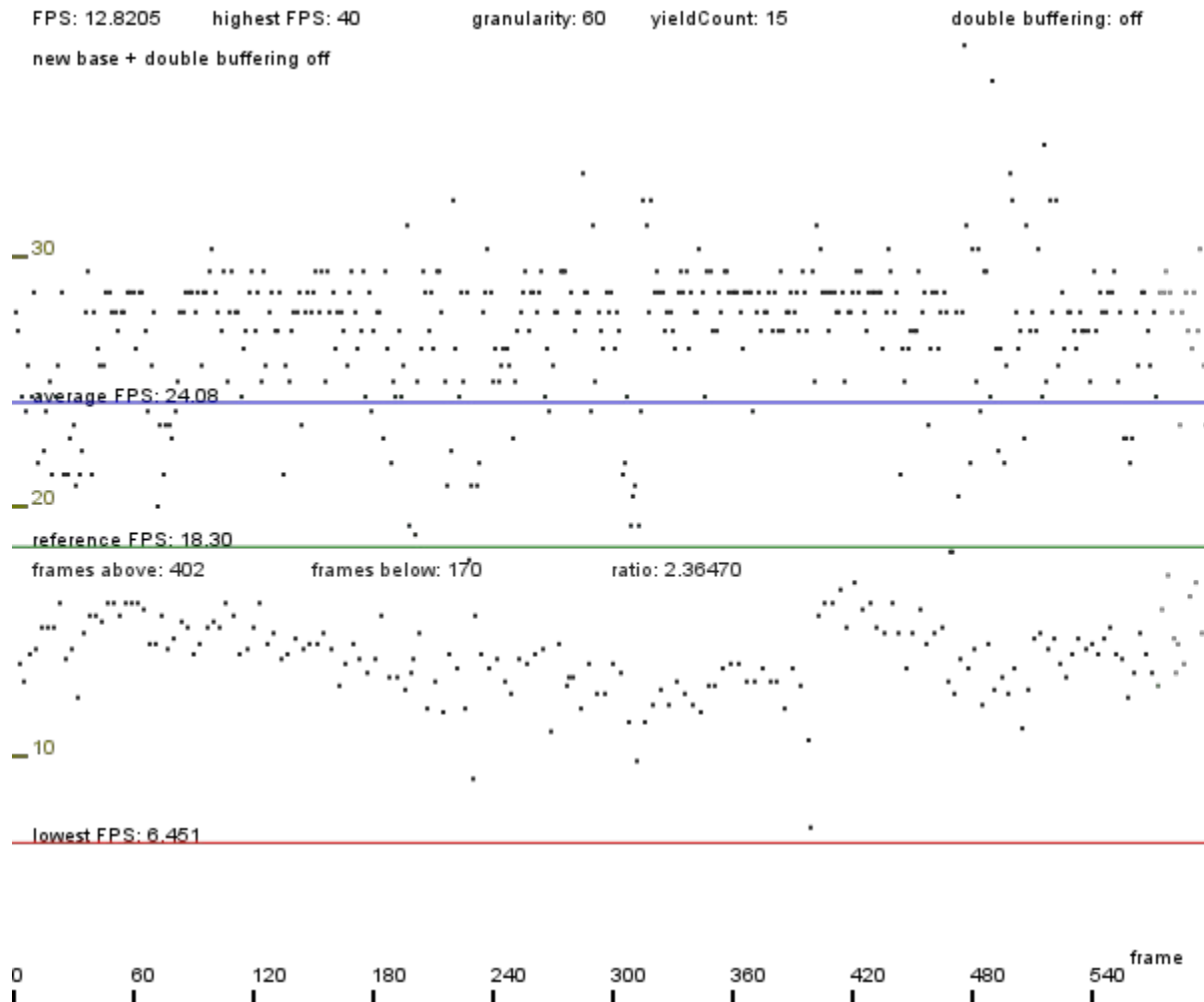


Chart 10: First two and the fourth optimization combined

Average FPS ~ 24.

Virtually no improvement over the two optimizations alone.

Garbage collector's behavior

The charts in this section were made using a modified version of the benchmark application – some variation of *performance2.links*.

To confirm that the GC is the cause of drops in FPS, I added a function that allows invoking Chromium's garbage collector on demand to Links. I put calls to this function after code that I thought was responsible for generating a lot of garbage – calling map on a big list (I forced 2 GC invocations per frame). This indeed, stabilized the framerate:

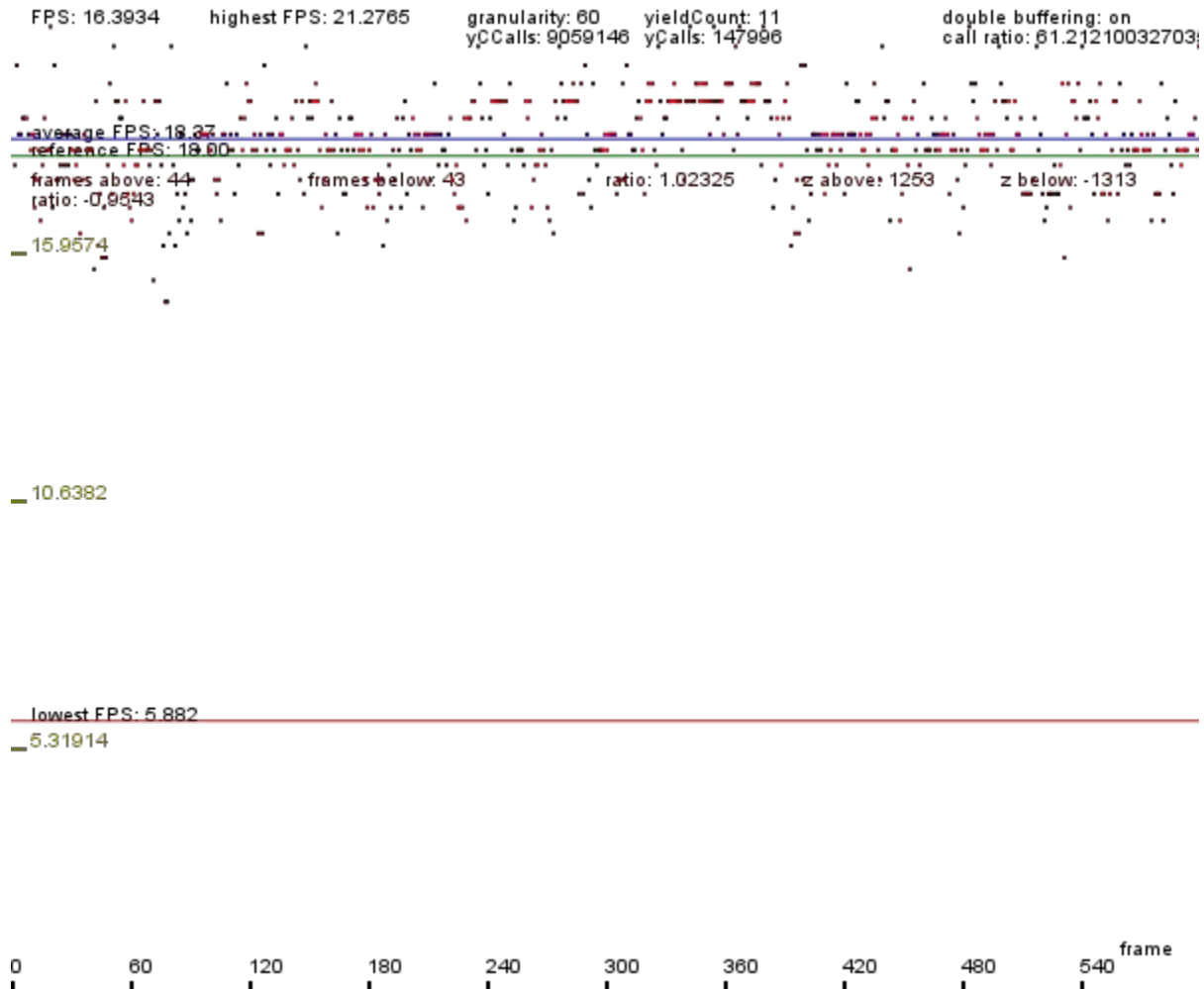


Chart 11: Invoking GC after mapping a function over a big list to clean up stabilizes the FPS; optimizing the implementation of map may significantly boost the performance

When I increased `_yieldGranularity` too much, the pattern on the chart changed – GC was invoked more often. Probably because the bigger the stack grows, the more garbage accumulates.

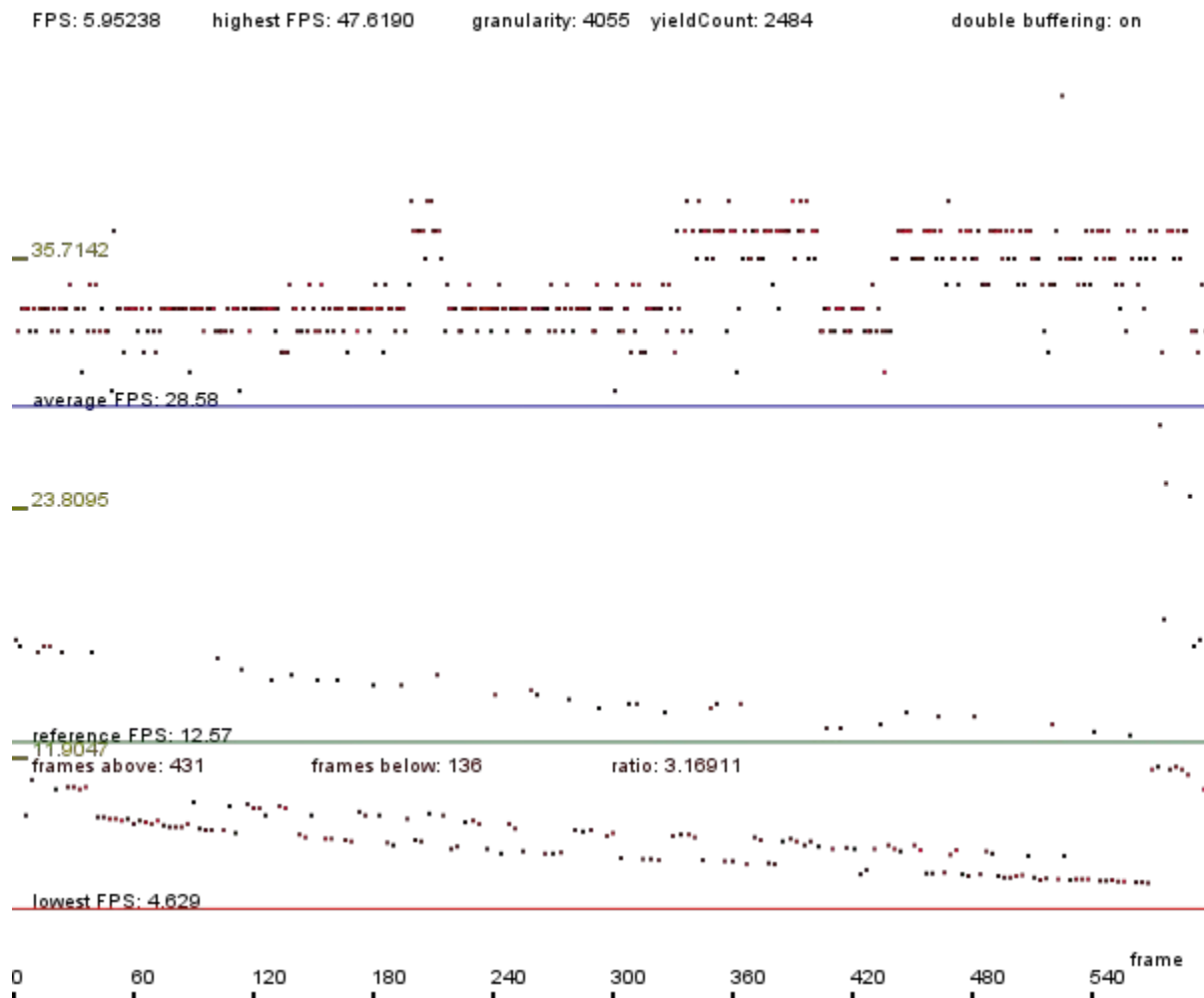


Chart 12: Too high `_yieldGranularity` results in more GC slowdowns

More optimizations and profiling

This section describes various other optimizations that I attempted. It also includes a comparison of the benchmark with a native JavaScript implementation.

JavaScript Optimizer

I tried running the runtime (*jslib.js*) and the JavaScript generated by the Links compiler through the Google Closure Compiler¹⁴. This required some modifications to *jslib.js*, but I eventually got it running (the final input to the Closure Compiler is attached to this document as *google closure input.js*). The effects are presented below:

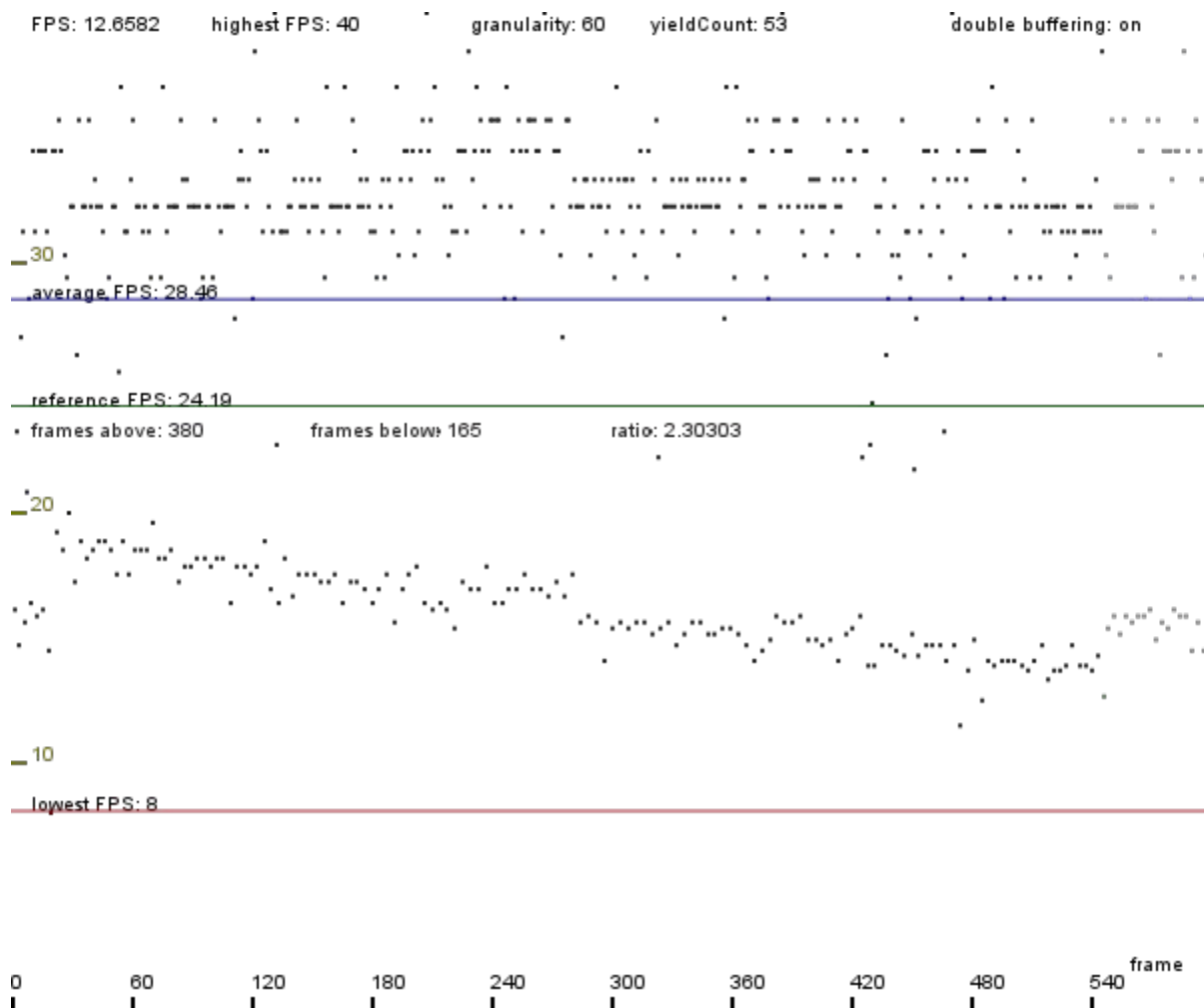


Chart 13: Performance of the **unoptimized** code

14 <https://developers.google.com/closure/>

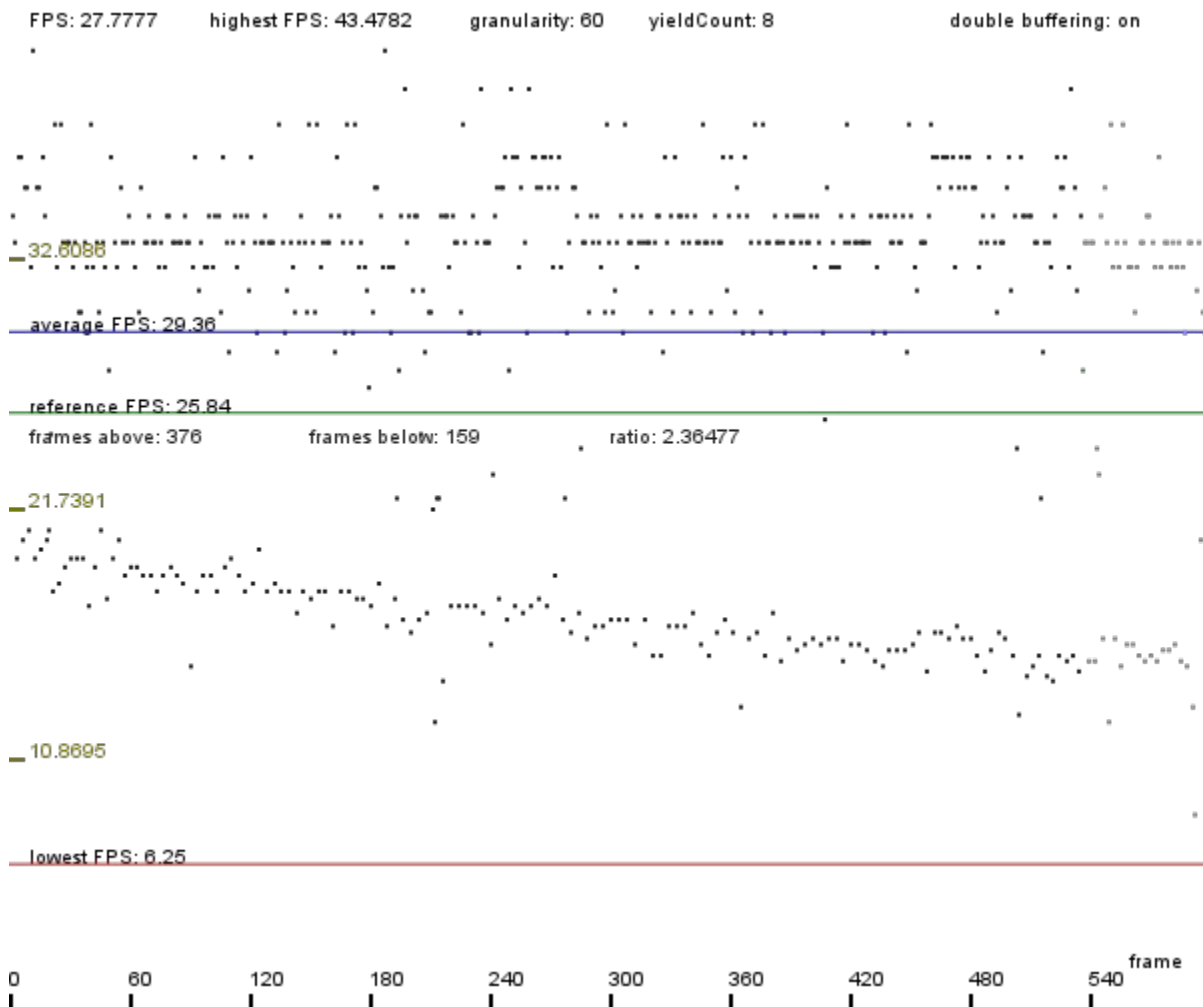


Chart 14: Performance of the code **optimized** with the Closure Compiler

We can notice a very slight improvement. I tested the code multiple times, also on Firefox. The effect was consistent.

Although this optimization didn't improve the performance significantly in this case, running the output of the compiler through an optimizer can be beneficial for bigger applications.

The next two charts present the comparison of profiling timeline plots (note the heap size – the blue line) between the original and the optimized code.

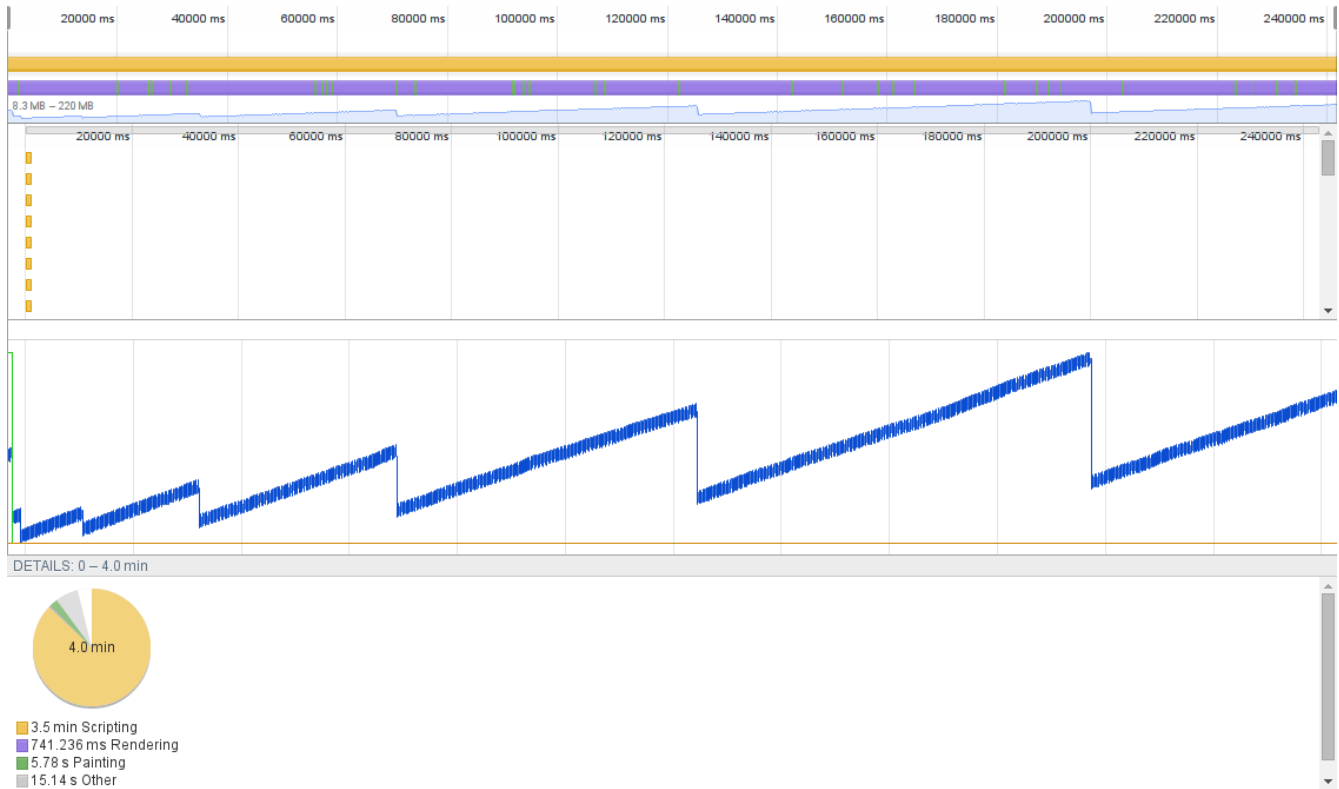


Chart 15: Chromium profiling timeline plot for **unoptimized** code

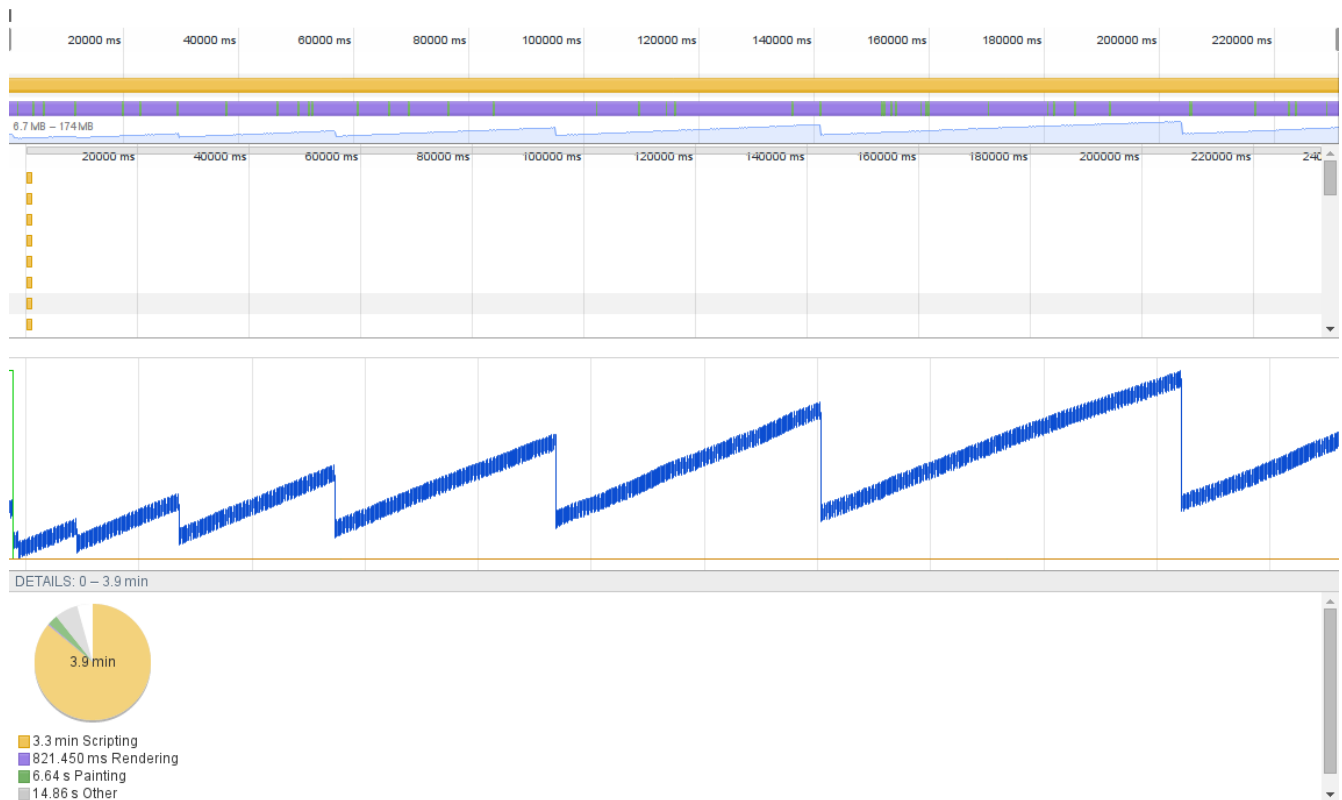


Chart 16: Chromium profiling timeline plot for code ***optimized*** with the Closure Compiler

Again, we see no significant difference. Perhaps a slight improvement.

Comparison with the native verison

It's also interesting to compare the previous timelines with a timeline for the native JavaScript version of the benchmark:

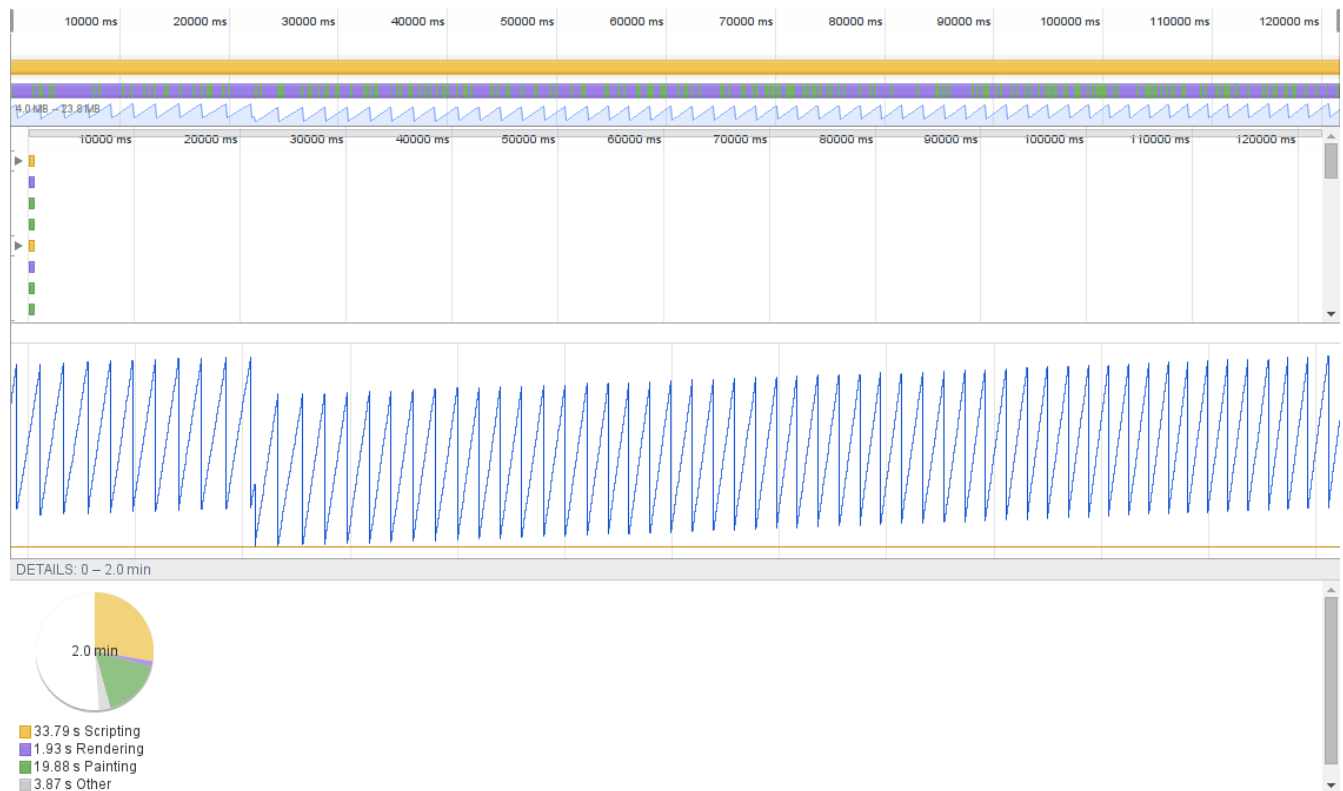


Chart 17: Timeline for the native JavaScript version

We see that much less garbage is being generated (about 4 times less garbage is being collected per GC event). The garbage collector slowdowns have no significant impact on performance in this case.

Compare also the heap allocation record:

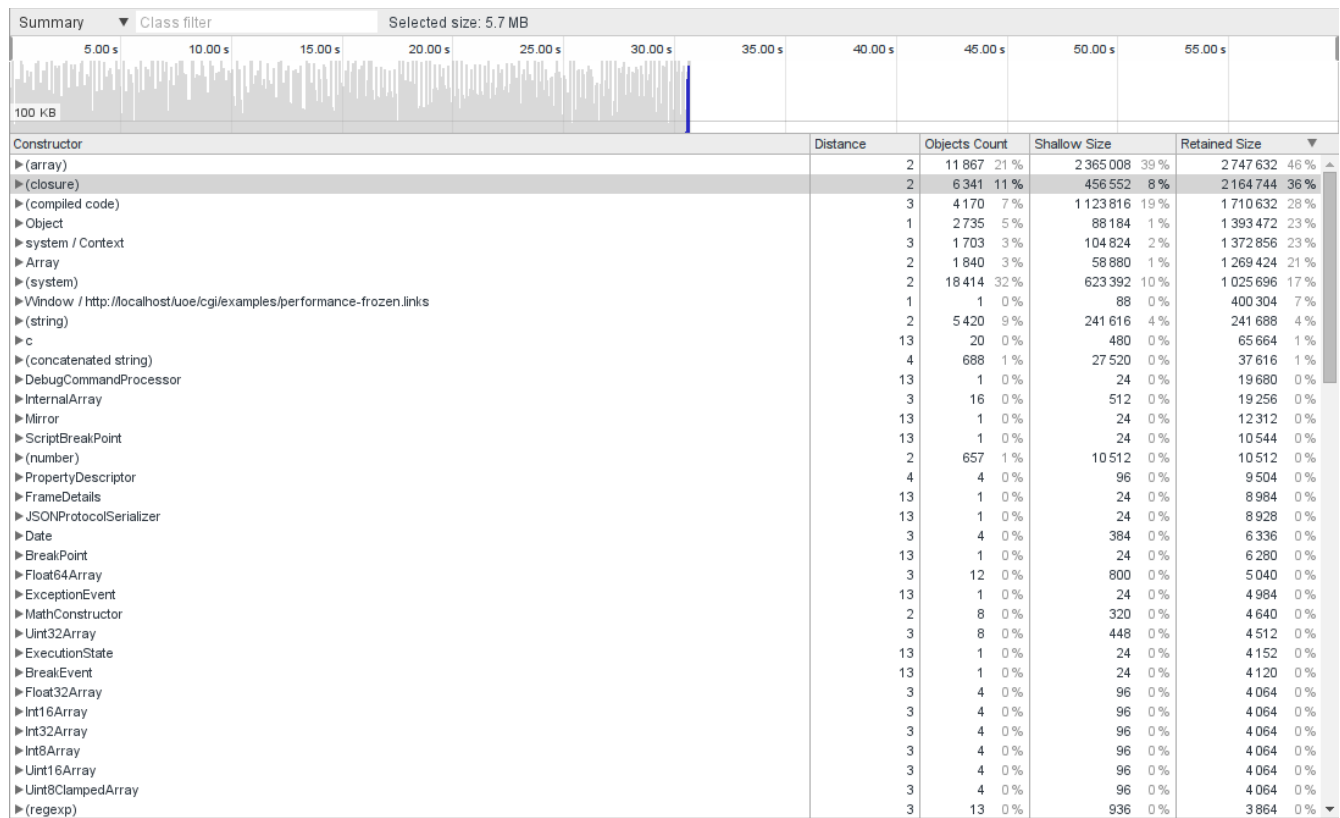


Chart 18: Unoptimized version – heap allocations

We see that very large amounts of memory are being allocated and collected.

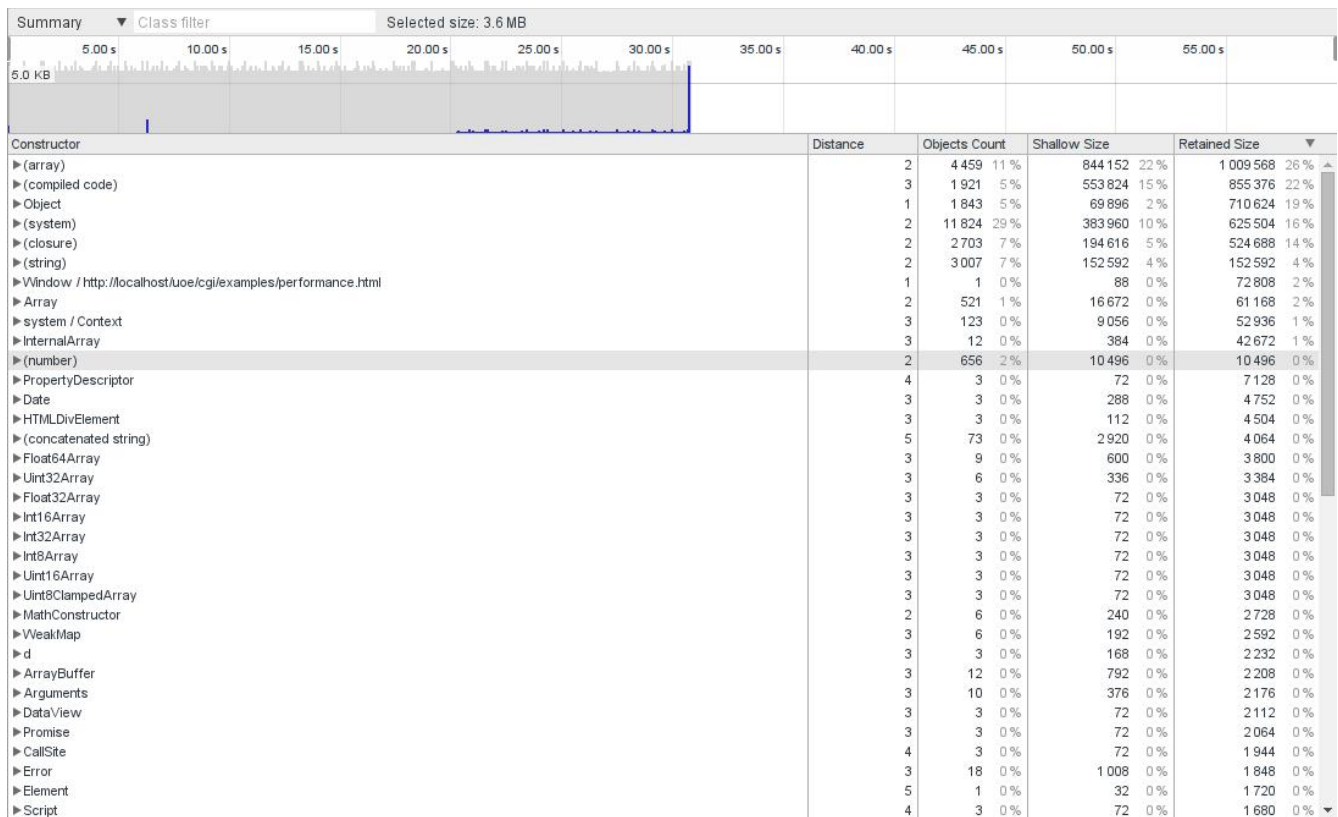


Chart 19: Native JavaScript version – heap allocations

We see that the size of the heap is much smaller, there's much less memory objects being generated and there are no spikes (the reference line here is at 5 KB and in the previous chart it was at 100 KB and went up to 5 times higher than that so the amount of memory allocated is at times 100 times greater in Links version).

The chart produced by the JavaScript version (note that double buffering is off, because it's unnecessary; also the framerate is limited to 60 FPS – frames are drawn using `requestAnimationFrame`¹⁵):

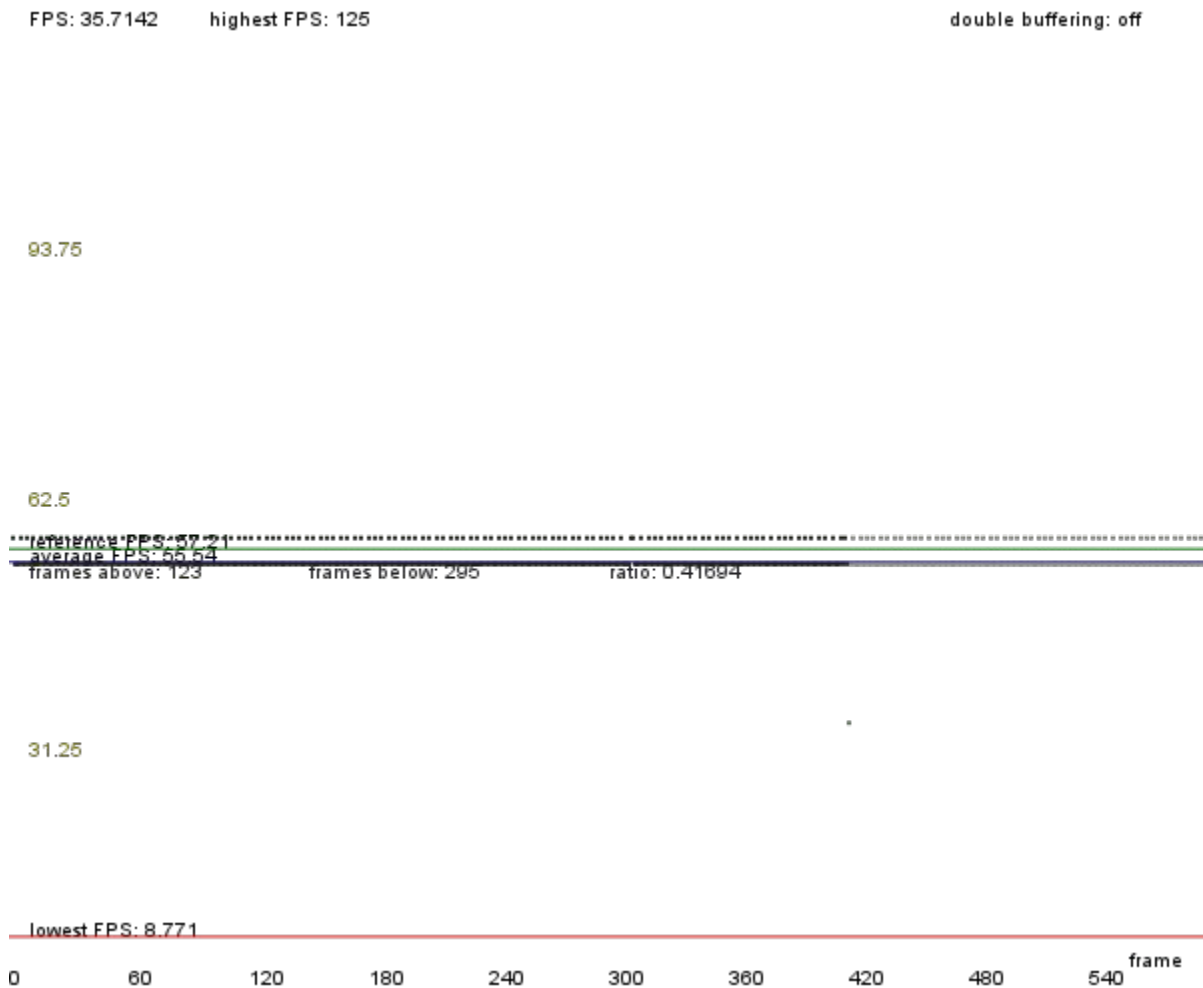


Chart 20: A chart generated by the JavaScript version of the benchmark

We see that in this case the FPS is stable – around 60, as expected.

¹⁵ <https://developer.mozilla.org/en/docs/Web/API/window.requestAnimationFrame>

Profiling

Profiling the execution time of any Links application gives similar results (this is a Firebug output for my Breakout clone):

<code>_yield</code>	72173	12.57%	3520.344ms	441966.667ms	6.124ms	0.069ms	64.442ms
<code>LINKS</LINKS.eq</code>	42105	8.31%	2327.104ms	6600.942ms	0.157ms	0.016ms	29.873ms
<code>DEBUG</<.is_array</code>	65154	7.52%	2104.892ms	3433.801ms	0.053ms	0.049ms	2.932ms
<code>_yieldCont</code>	59419	7.03%	1968.201ms	326011.922ms	5.487ms	0.049ms	64.531ms
<code>___append</code>	72172	5.42%	1516.437ms	1516.437ms	0.021ms	0.018ms	3.805ms
<code>is_instance</code>	65154	4.75%	1328.909ms	1328.909ms	0.02ms	0.019ms	0.531ms
<code>_Concat</code>	38344	4.43%	1239.774ms	2089.944ms	0.055ms	0.049ms	8.437ms
<code>LINKS</LINKS.concat</code>	38344	3.04%	850.171ms	850.171ms	0.022ms	0.019ms	8.385ms
<code>_Cons</code>	23690	2.72%	760.763ms	2051.792ms	0.087ms	0.08ms	8.471ms
<code>concatMap</code>	9767	2.36%	661.824ms	59392.895ms	6.081ms	0.311ms	57.352ms
<code>DEBUG</<.is_unit</code>	34230	2.26%	631.935ms	631.935ms	0.018ms	0.016ms	0.087ms
<code>_tl</code>	28668	2.04%	571.488ms	571.488ms	0.02ms	0.018ms	1.526ms
<code>fold_left</code>	9543	1.9%	531.448ms	50745.051ms	5.318ms	0.137ms	63.218ms
<code>_hd</code>	28668	1.89%	529.918ms	529.918ms	0.018ms	0.017ms	1.017ms
<code>concatMap/<</code>	9385	1.62%	452.956ms	54224.969ms	5.778ms	0.172ms	26.463ms
<code>concatMap/</</</<</code>	9385	1.56%	435.489ms	47863.003ms	5.1ms	0.172ms	34.252ms
<code>map</code>	5051	1.14%	318.988ms	29698.037ms	5.88ms	0.319ms	64.784ms
<code>concatMap/</<</code>	9385	1.14%	318.981ms	53585.898ms	5.71ms	0.106ms	26.394ms
<code>concatMap/</</<</code>	9385	1.13%	315.353ms	56259.066ms	5.995ms	0.106ms	57.473ms
<code>zip</code>	4628	1.11%	311.201ms	64499.496ms	13.937ms	0.527ms	62.428ms
<code>foldStep_1873/</<</code>	4501	1.04%	290.569ms	21938.159ms	4.874ms	0.272ms	17.764ms
<code>zip/</<</code>	4501	1.02%	285.234ms	62251.253ms	13.831ms	0.432ms	62.071ms
<code>map/<</code>	4788	0.83%	232.334ms	25953.619ms	5.421ms	0.173ms	23.582ms

Obviously `_yield` and `_yieldCont` take the most overall time and are called the most often. A lot of list operations means calling a lot of functions that manipulate them, which are also quite costly.

Functions that are potential candidates for optimization:

- `LINKS.eq` – the compiler should make use of type information and generate specialized code for comparing things, instead of just using a general runtime function
- `map` and other list manipulating functions (`take`, `drop`, `zip`, `hd`, `tl`...) – the way lists are implemented (right now they are just JavaScript arrays) should be changed and all functions operating on lists should be adjusted to that more efficient implementation; that would be a major improvement in performance

Other optimizations

Other optimizations I tried out were:

- Using a much (up to 10x) faster implementation of queues¹⁶ – I tested that with `setZeroTimeout` (uses a queue for storing functions to be called) and with `_send` (! in Links' syntax) and `recv` (which use queues for process mailboxes), but it turned out to be not a big improvement, because of the generally small size of the queues (this faster implementation shows its advantages when used with bigger queues; for small ones the gain is cancelled out by the overhead);
 - Note: the current implementation of queues based on `unshift-pop` is up to 2 times slower¹⁷ than the implementation based on `push-shift` (at least in Firefox and Opera – in Chromium the `unshift-pop` seems to generally be a bit faster)
- Removing calls to debug functions from various places (like `_send`), which did improve the performance significantly; any calls to debug functions in often used code obviously may add up to a significant slowdown; I mostly removed calls to these functions:
 - `DEBUG.assert`
 - `DEBUG.assert_noisy`
 - `_debug`
 - `_dumpSchedStatus` – a very significant slowdown, unnecessarily executing code containing loops even if not in debug mode, everytime `_send` is called
- Using `Date.now()` instead of `new Date().getTime()` in `_clientTime()`

¹⁶ <http://code.stephenmorley.org/javascript/queues/>

¹⁷ <http://jsperf.com/queuing-push-shift-vs-unshift-pop>

Lists, equality and _yield optimizations

This section describes various other optimizations that I attempted. It also includes a comparison of the benchmark with a native JavaScript implementation.

Lists

Base

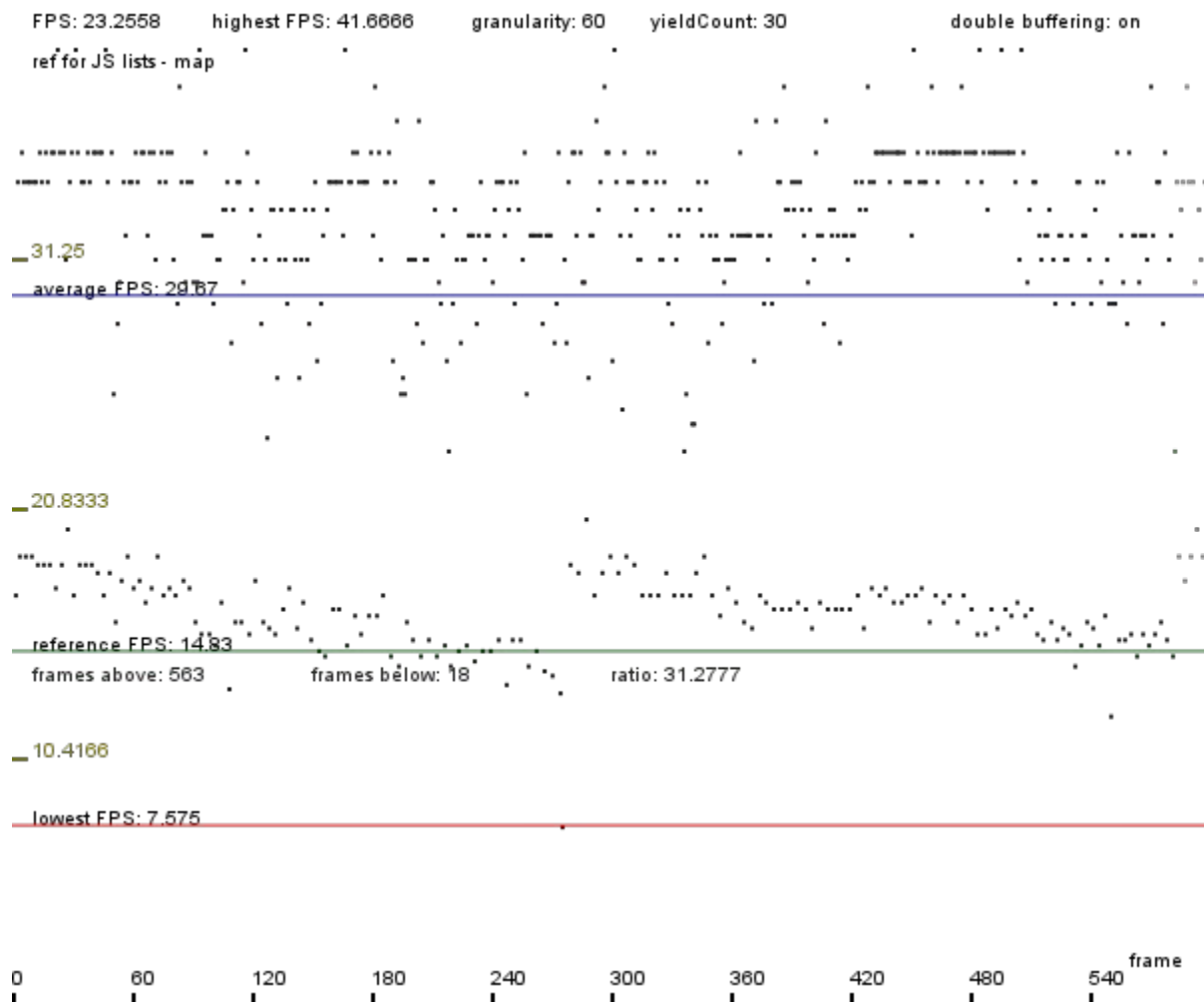


Chart 21: This is the reference for all charts that follow

Linked list type

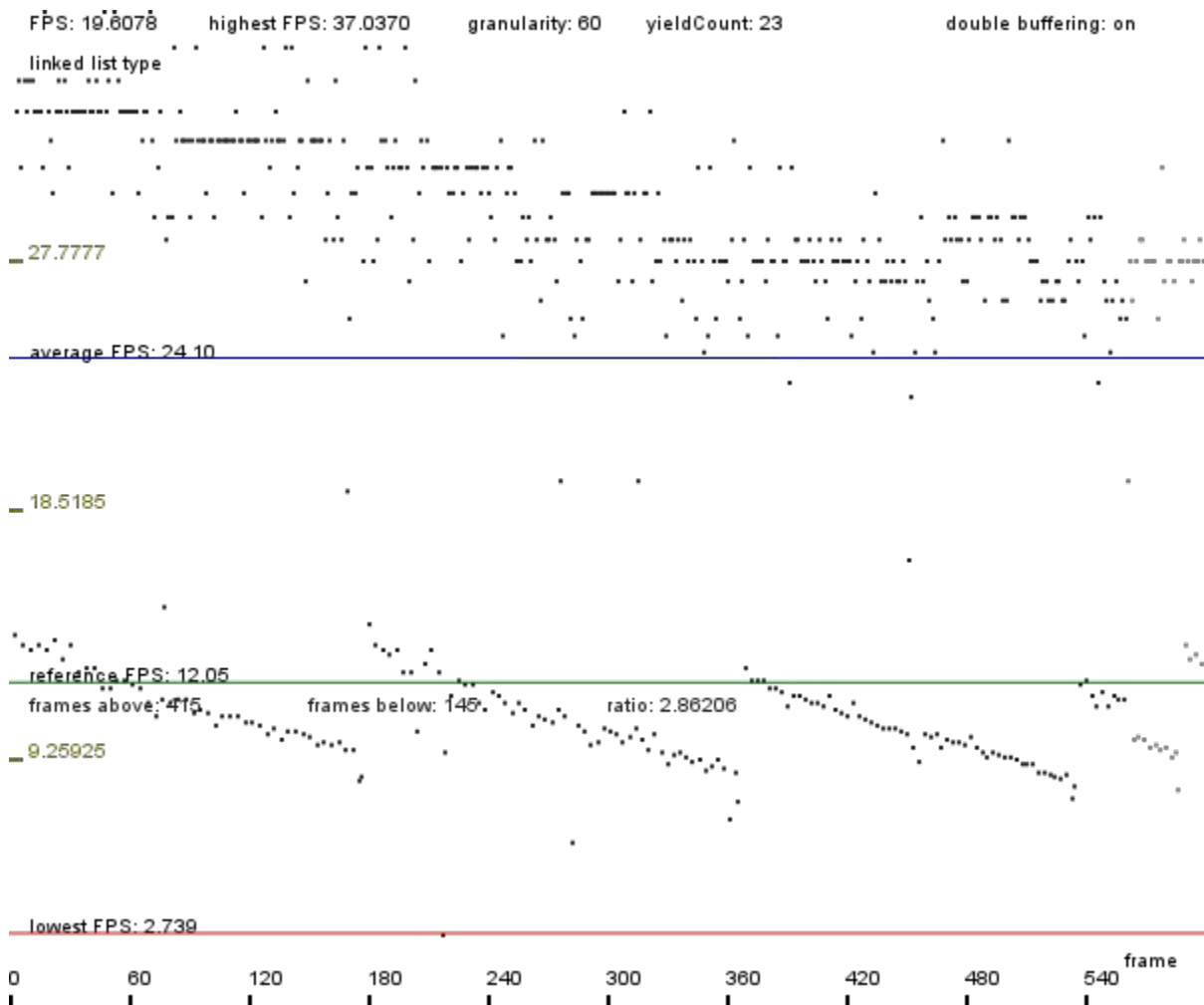


Chart 22: *Linked list type*

After replacing all Links lists with a custom list type, defined like so:

```
typename Ls(a) = mu l . [| Nil | Cn: (a, l) |];
```

we can see a drop in framerate and a lot more garbage being generated. Looks like the opposite of what we'd expect. There seems to be much more copying. [[elaborate]]

JavaScript linked lists with native take and drop

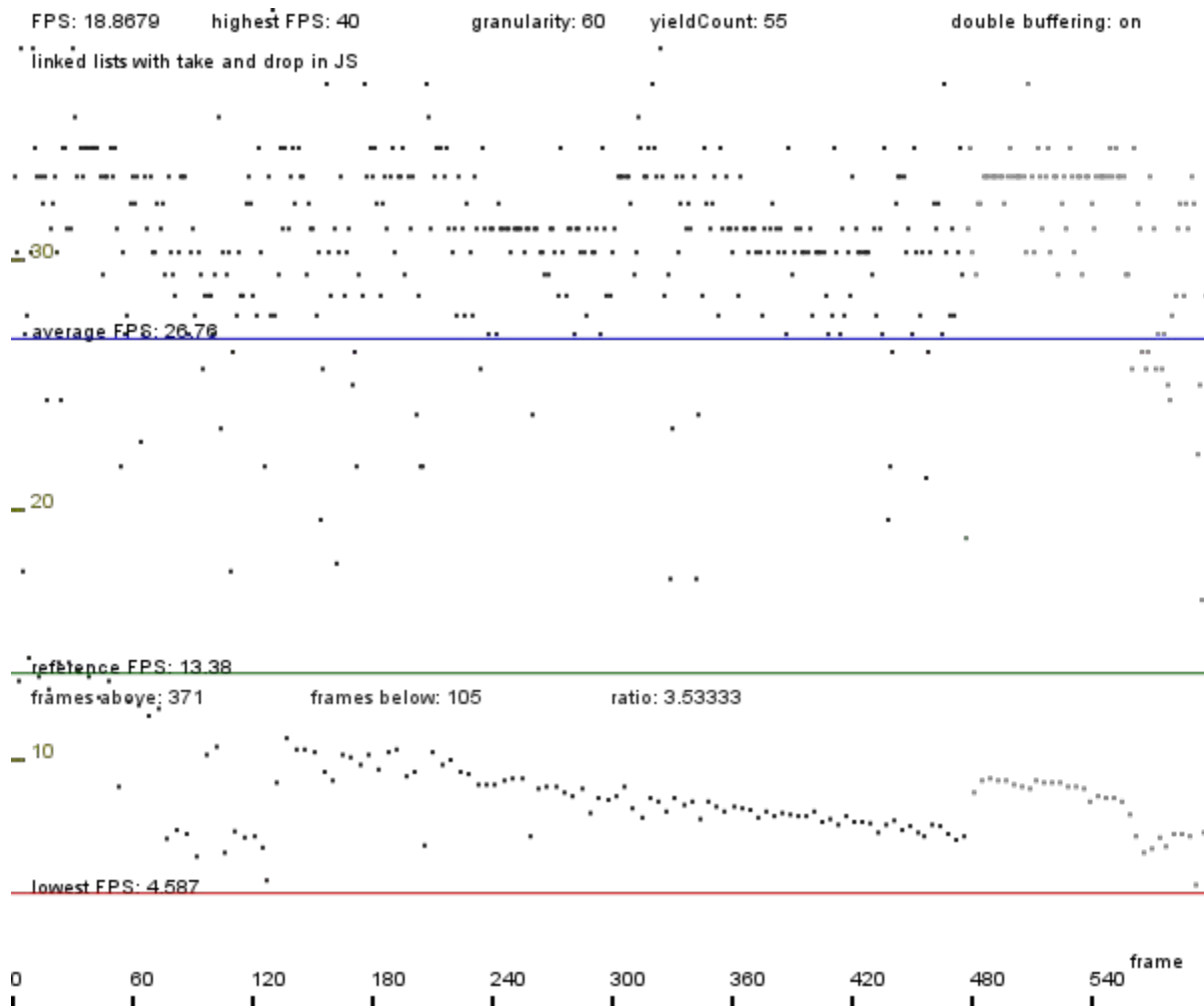


Chart 23: Linked lists with take and drop in JS

The most copying in the benchmark application is caused by take and drop functions (for the custom list type defined in Links as `lsTake` and `lsDrop`). If we replace them by optimized JavaScript versions, we indeed see some improvement, but still overall the performance decreased in comparison with the reference.

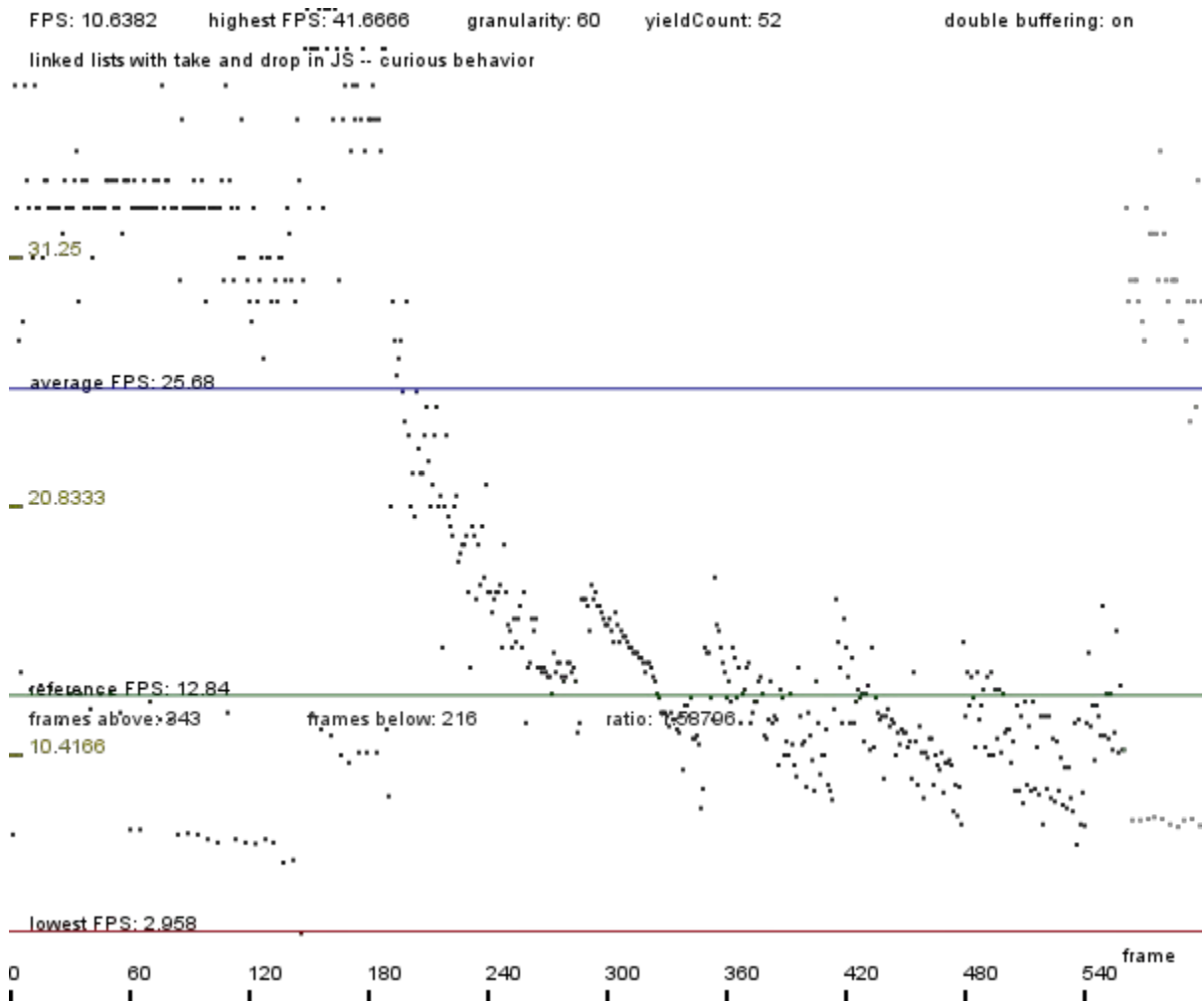


Chart 24: Same as before -- curious case

After over 8 iterations I also noticed this strange behaviour. I wasn't able to track down the cause, but I concluded that I will not rely on the list type defined in Links, but instead I'll implement my own, entirely in JavaScript.

JavaScript linked lists

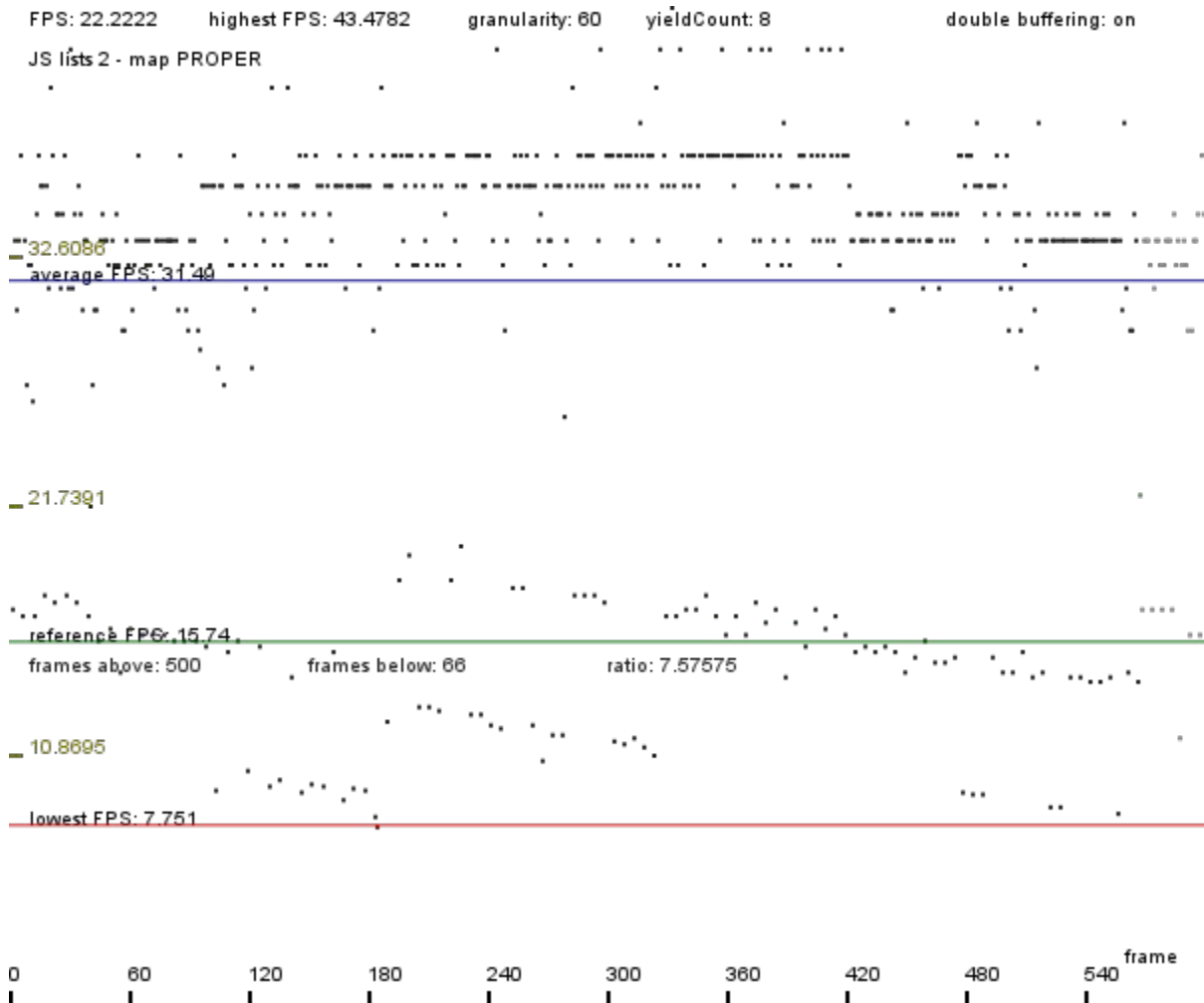
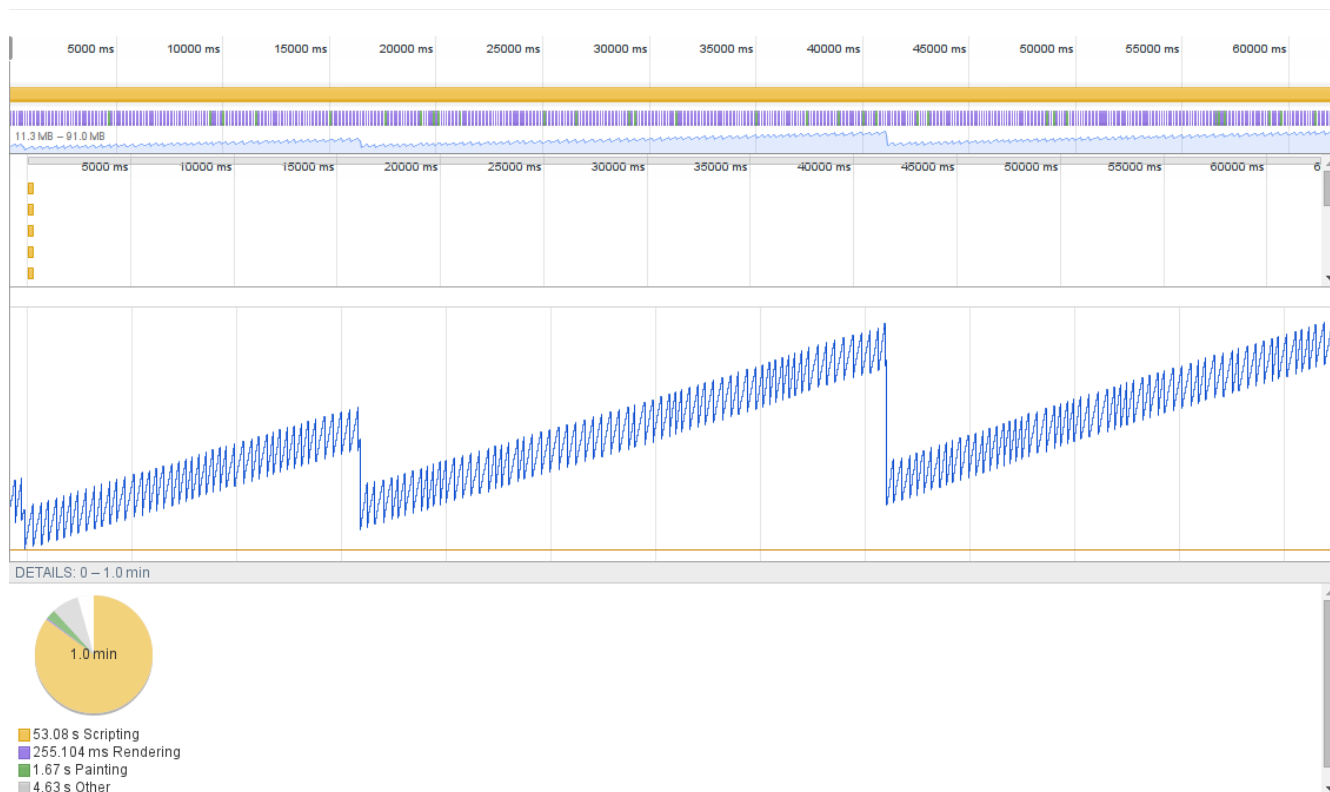
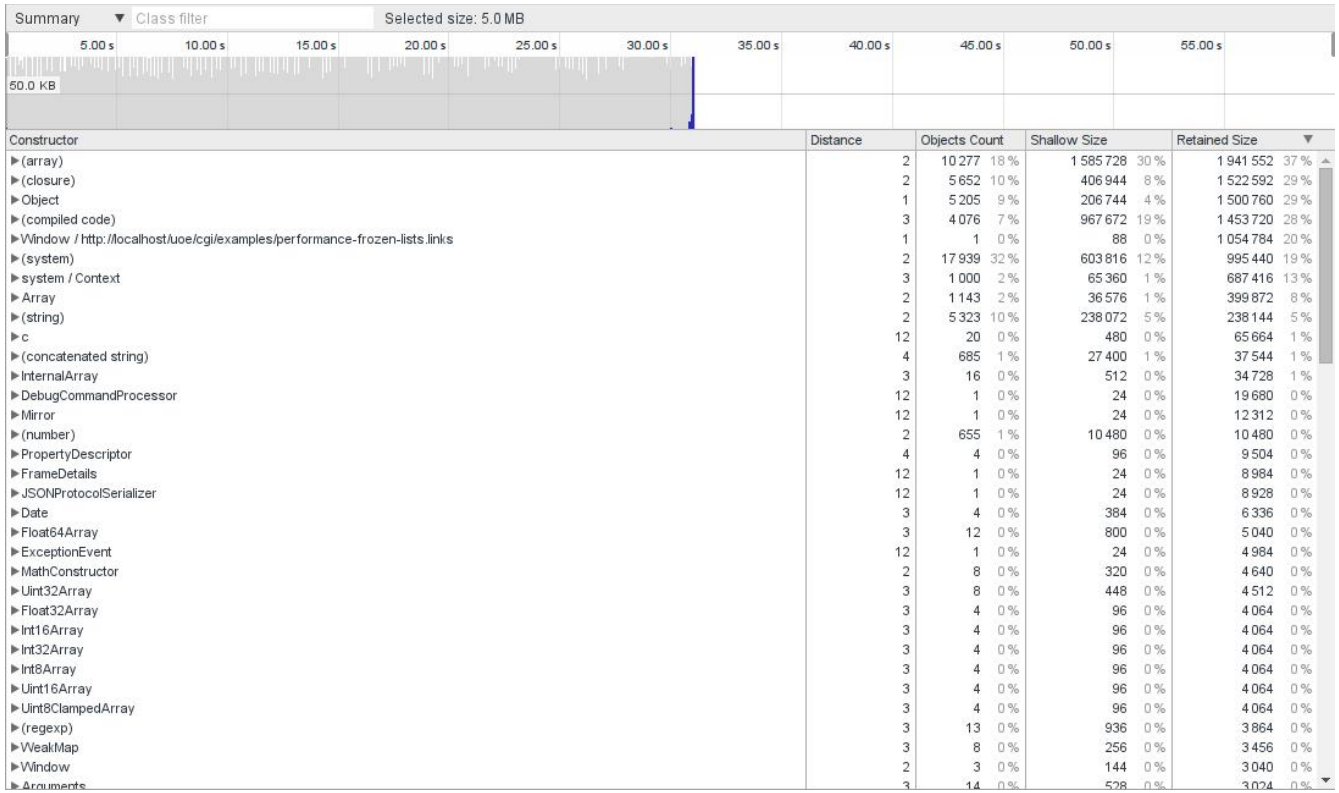


Chart 25: Linked lists in JS (no map*)

After replacing the list type with JavaScript implementation, we see a small improvement. The framerate goes up, the garbage collection count decreases a bit.



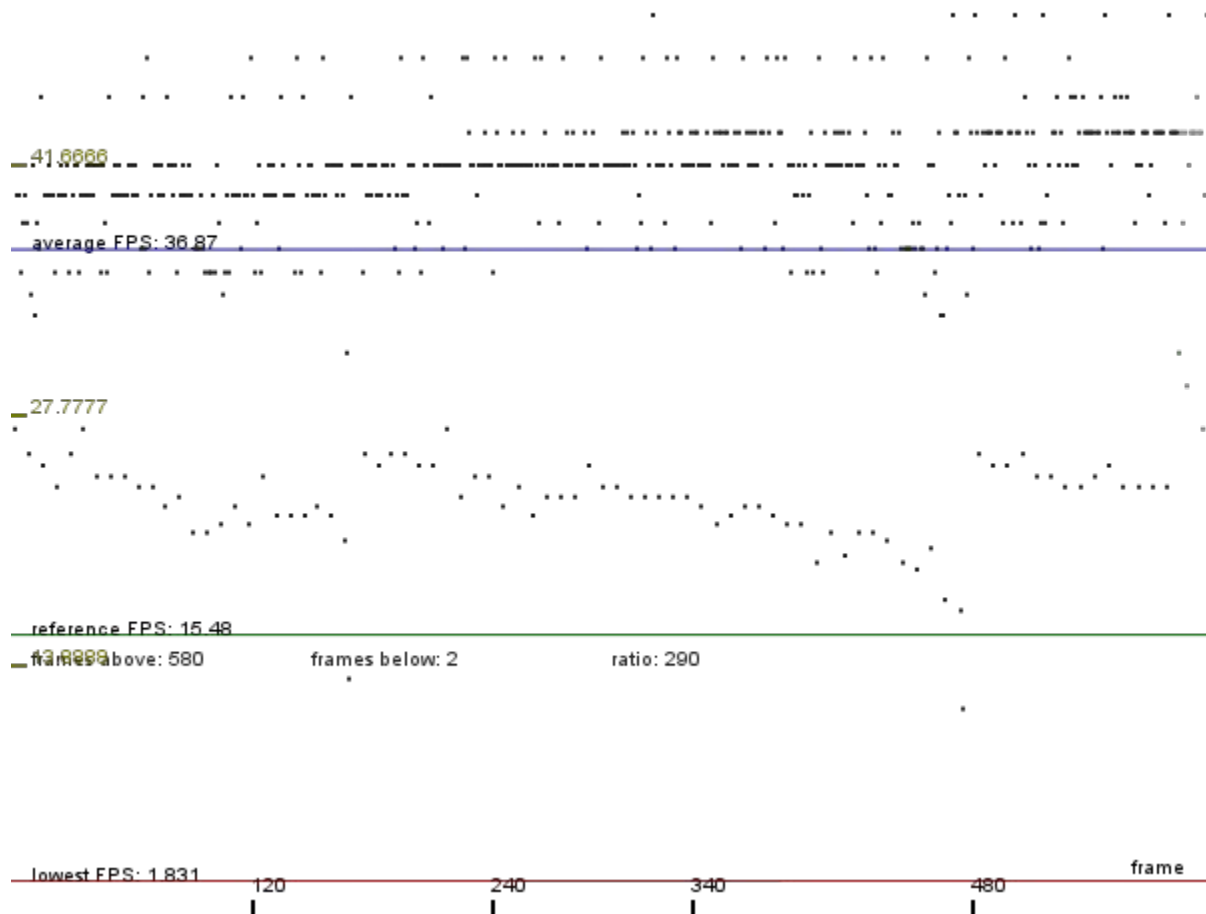


JS lists 3?

JS lists with null

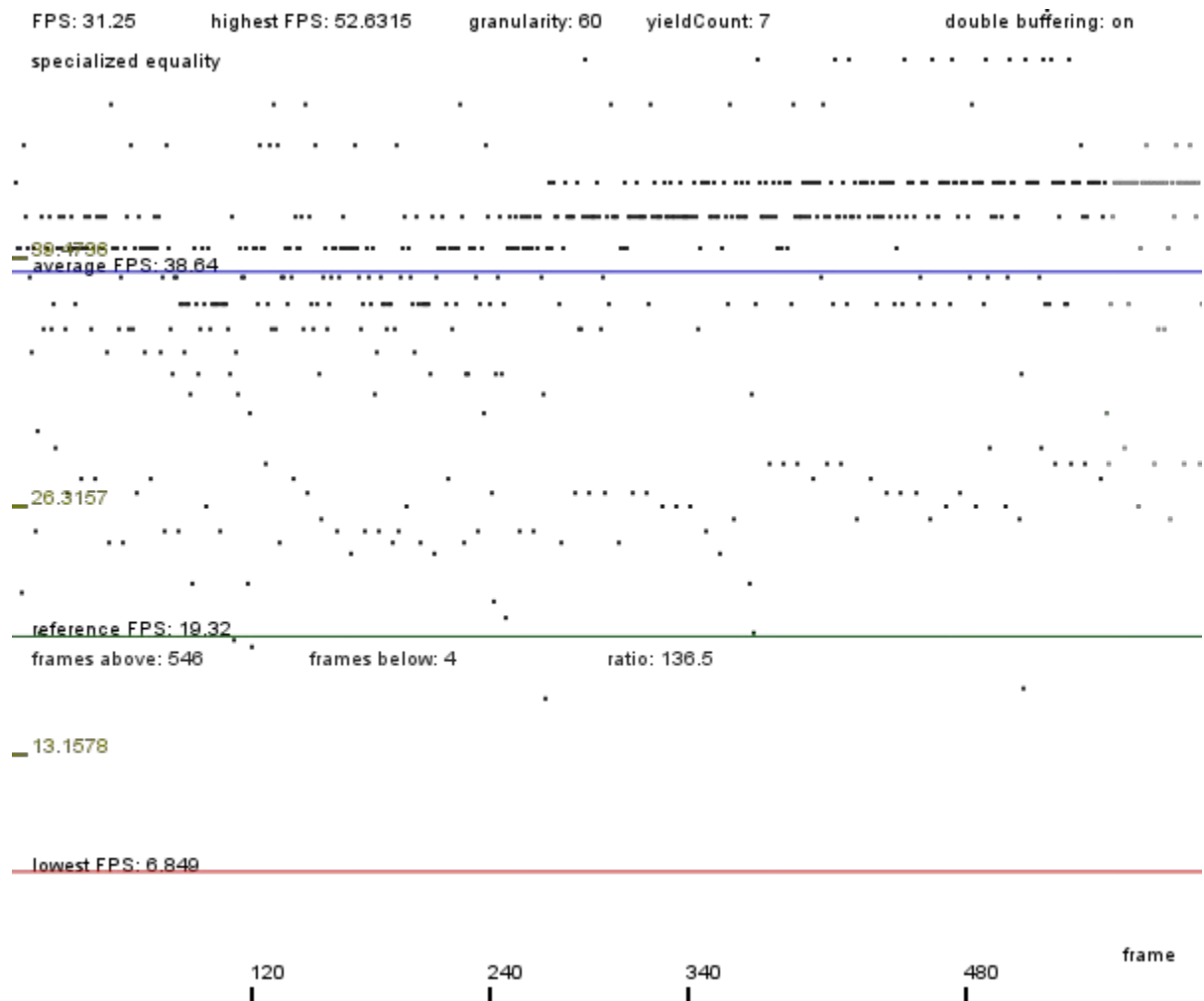
FPS: 31.25 highest FPS: 55.5555 granularity: 60 yieldCount: 22 double buffering: on

JS lists with null - map

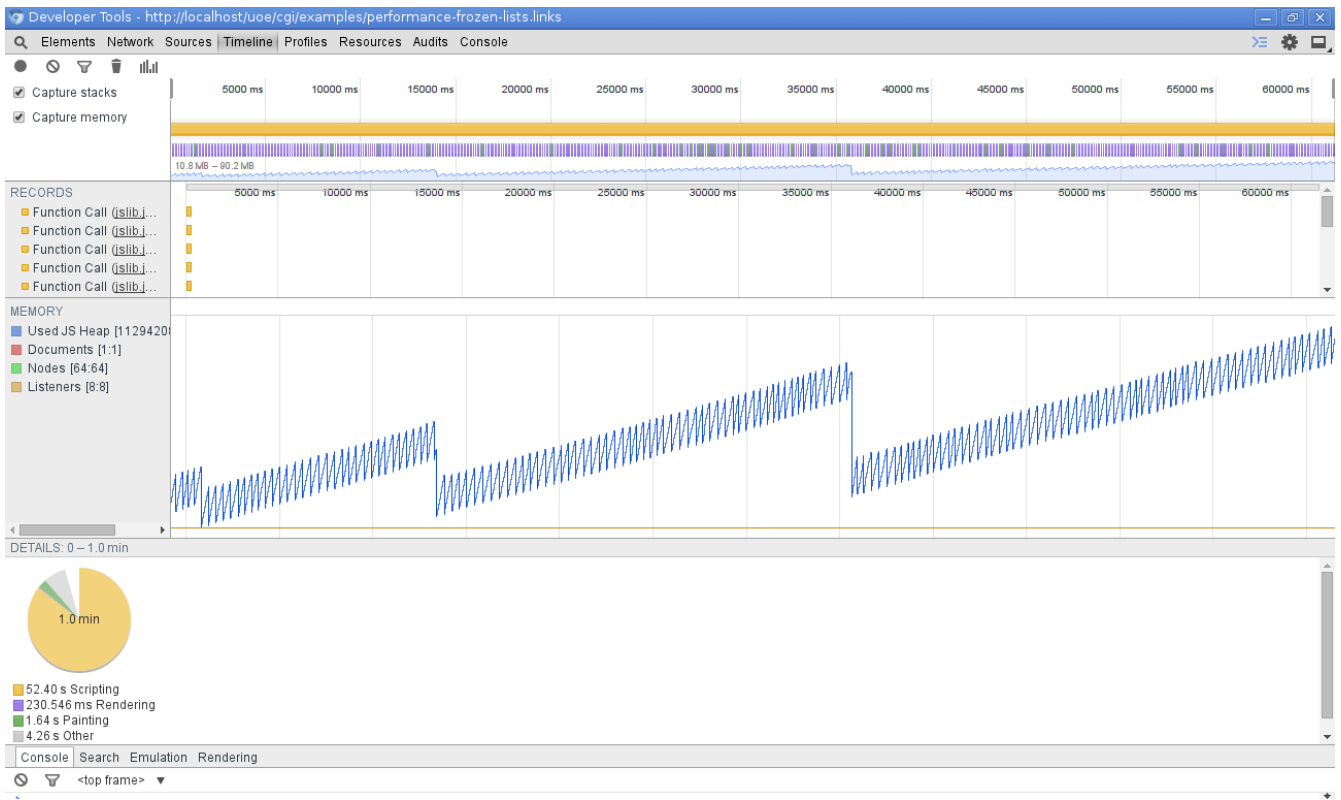


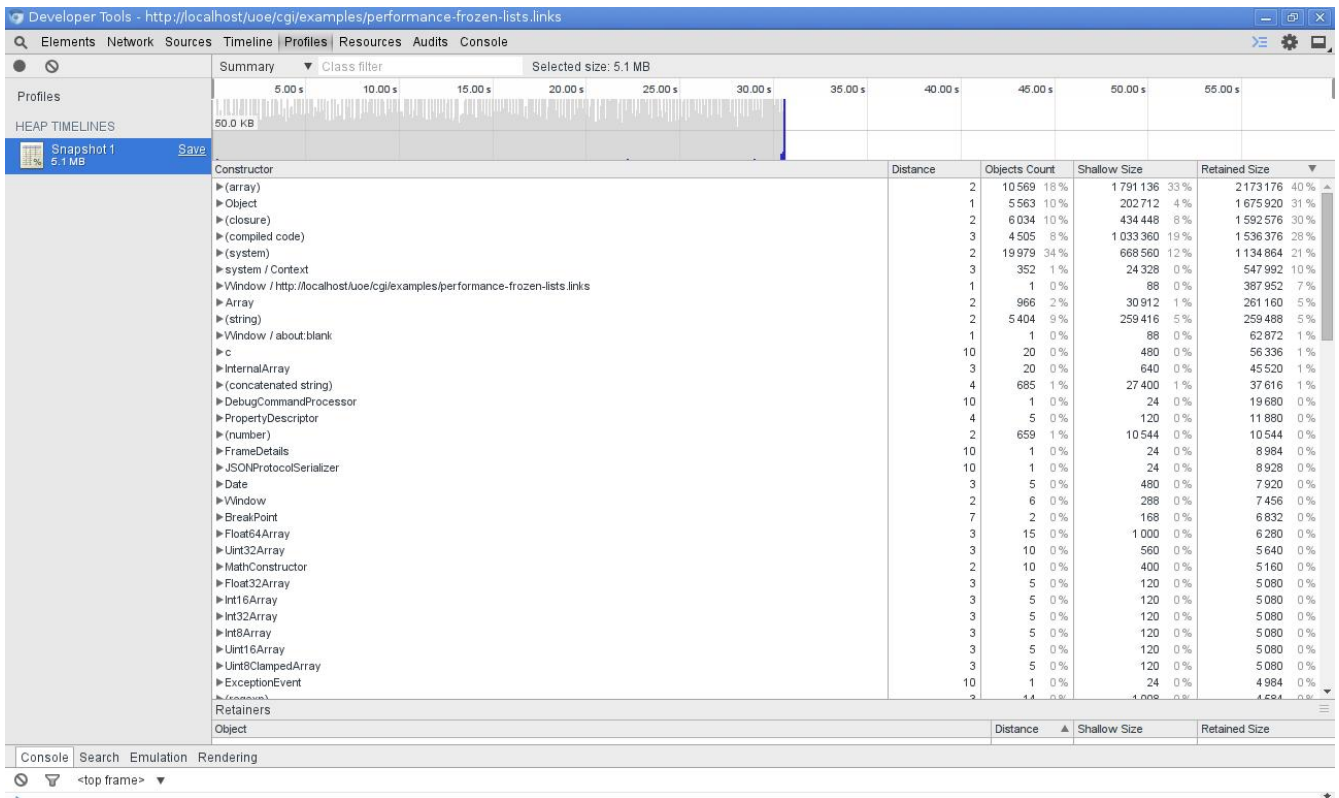
Further optimizations to the list type...

Equality



Specialized equality on top of the optimized linked list type.

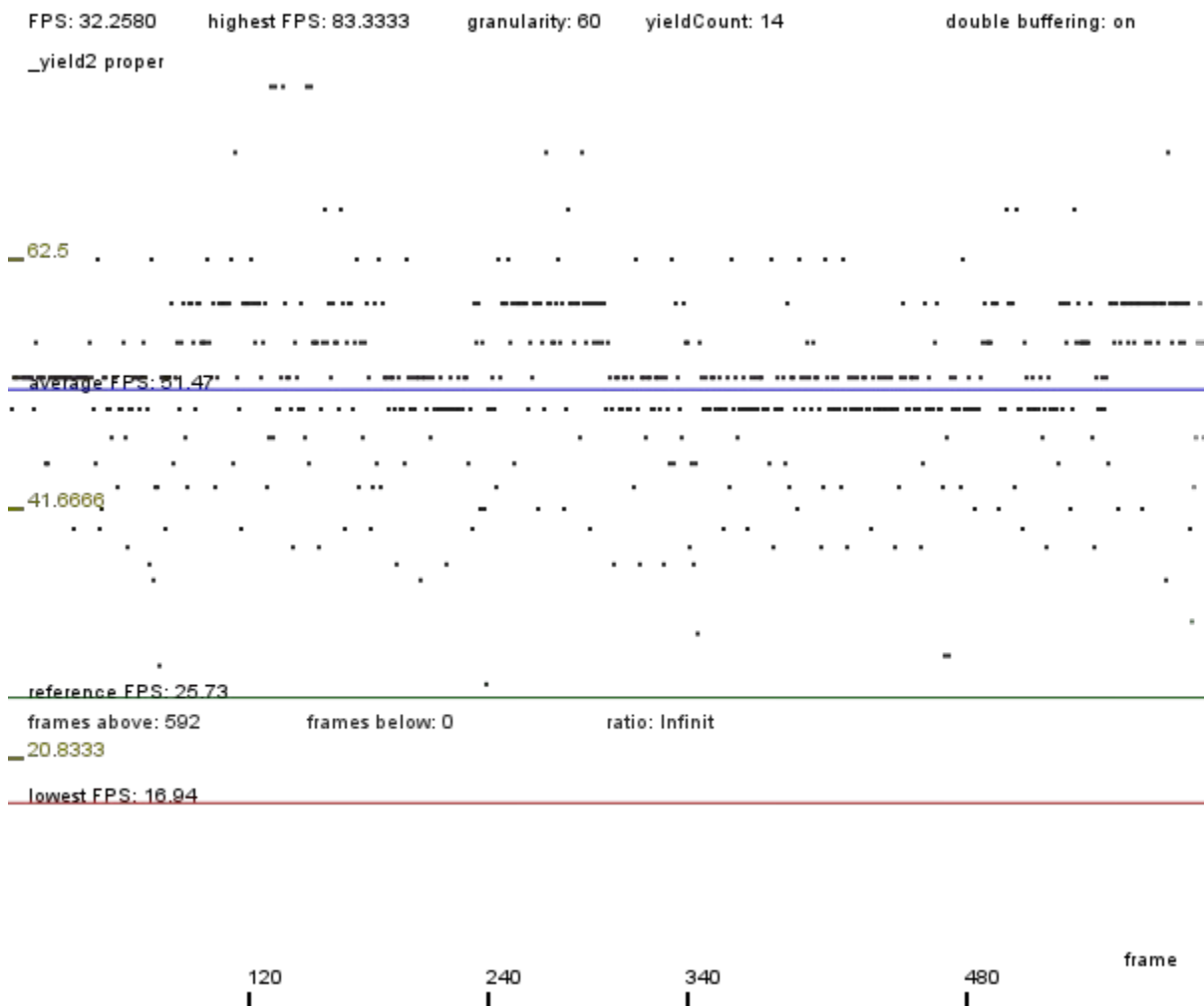




Function	Calls	Percent	Own Time	Time	Avg	Min	Max	File
_yield	137180	22.97%	7085.719ms	477872.583ms	3.484ms	0.076ms	118.495ms	jslib.js (line 2098)
_yieldCont	109960	12.76%	3936.668ms	393977.801ms	3.583ms	0.075ms	118.682ms	jslib.js (line 2122)
__append	137180	10.98%	3387.833ms	3387.833ms	0.025ms	0.021ms	110.323ms	jslib.js (line 1993)
lsMapIgnore	23521	4.87%	1502.319ms	83213.99ms	3.538ms	0.147ms	91.952ms	perform...s.links (line 1897)
putPixel	26101	4.02%	1239.515ms	89203.568ms	3.418ms	0.17ms	118.784ms	perform...s.links (line 1908)
lsMapIgnore/</>	23081	3.65%	1125.141ms	82204.579ms	3.562ms	0.143ms	92.127ms	perform...s.links (line 1904)
scalePoint_1690	24181	3.01%	929.178ms	82979.916ms	3.432ms	0.113ms	118.122ms	perform...s.links (line 2028)
putPixel/<	26101	2.75%	848.897ms	87478.673ms	3.352ms	0.107ms	118.717ms	perform...s.links (line 1912)
plotPoint_1741/<	23861	2.67%	825.009ms	82418.115ms	3.454ms	0.112ms	118.042ms	perform...s.links (line 2115)
plotPoint_1741	23861	2.65%	818.001ms	79416.593ms	3.328ms	0.111ms	118.235ms	perform...s.links (line 2113)
lsMapIgnore/<	23081	2.59%	800.367ms	80934.866ms	3.507ms	0.111ms	91.115ms	perform...s.links (line 1903)
plotPoint_1741/</>	23861	2.51%	775.149ms	81955.139ms	3.435ms	0.108ms	118.645ms	perform...s.links (line 2118)
ignore	23161	2.48%	766.367ms	78996.921ms	3.411ms	0.108ms	90.987ms	perform...s.links (line 711)
_lsCons	35980	2.45%	754.891ms	754.891ms	0.021ms	0.018ms	43.048ms	jslib.js (line 2656)
_lsTail	26301	1.81%	559.628ms	559.628ms	0.021ms	0.017ms	81.366ms	jslib.js (line 2704)
_lsEmpty	28760	1.6%	495.133ms	495.133ms	0.017ms	0.016ms	0.082ms	jslib.js (line 2776)
_jsFillRect	26101	1.57%	485.38ms	485.38ms	0.019ms	0.017ms	0.67ms	jslib.js (line 2528)
_lsHead	26381	1.53%	473.475ms	473.475ms	0.018ms	0.016ms	0.593ms	jslib.js (line 2703)
_lsFromArray	80	1.28%	396.103ms	975.939ms	12.199ms	2.14ms	64.732ms	jslib.js (line 2659)
handleMessage	4535	0.73%	224.342ms	30851.288ms	6.803ms	0.179ms	118.923ms	jslib.js (line 15)
lsMap	3260	0.7%	217.486ms	12019.063ms	3.687ms	0.175ms	118.415ms	perform...s.links (line 1866)
_objectEq	12034	0.7%	214.571ms	214.571ms	0.018ms	0.016ms	0.07ms	jslib.js (line 2849)
setZeroTimeout	4535	0.67%	207.151ms	207.151ms	0.046ms	0.034ms	0.538ms	islib.js (line 10)

`_yield`

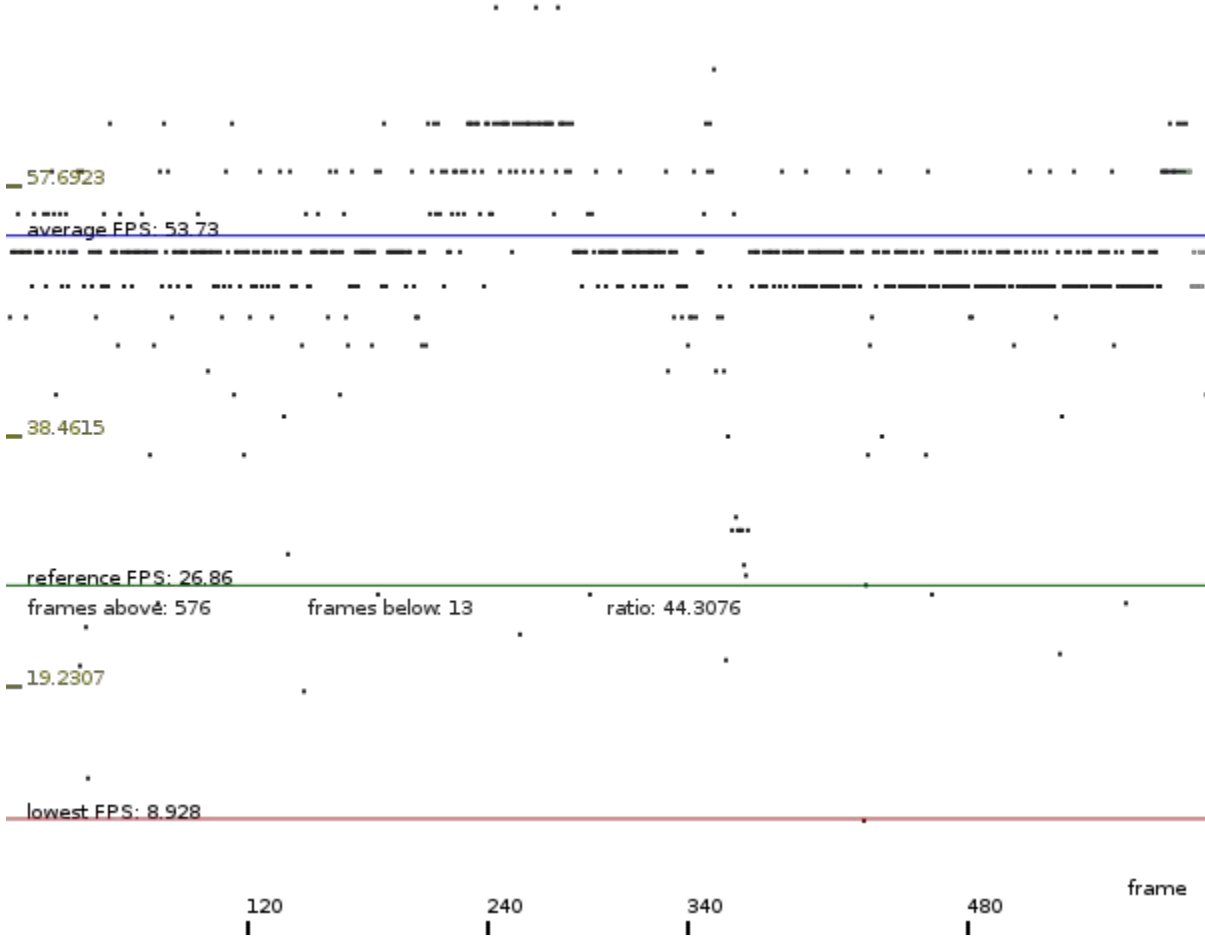
Chromium



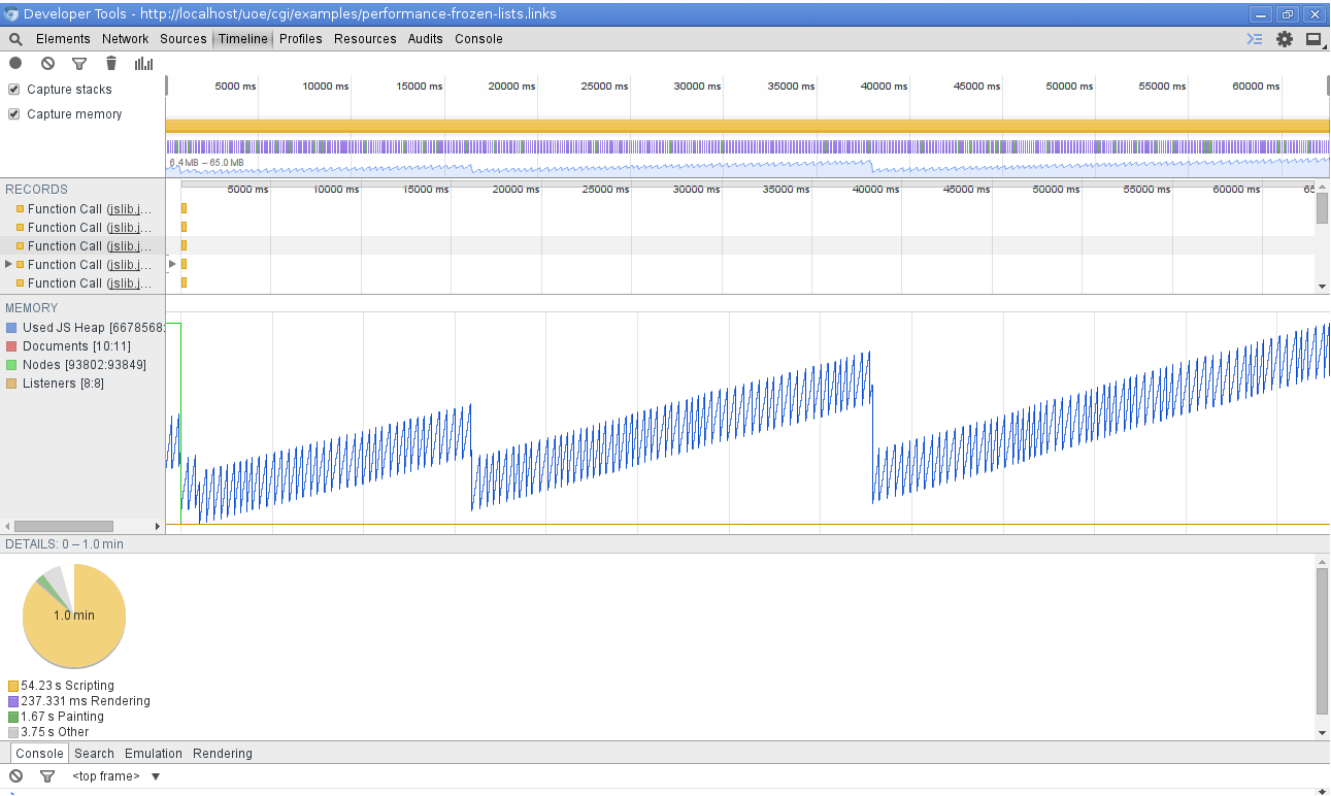
Optimized version of `_yield`.

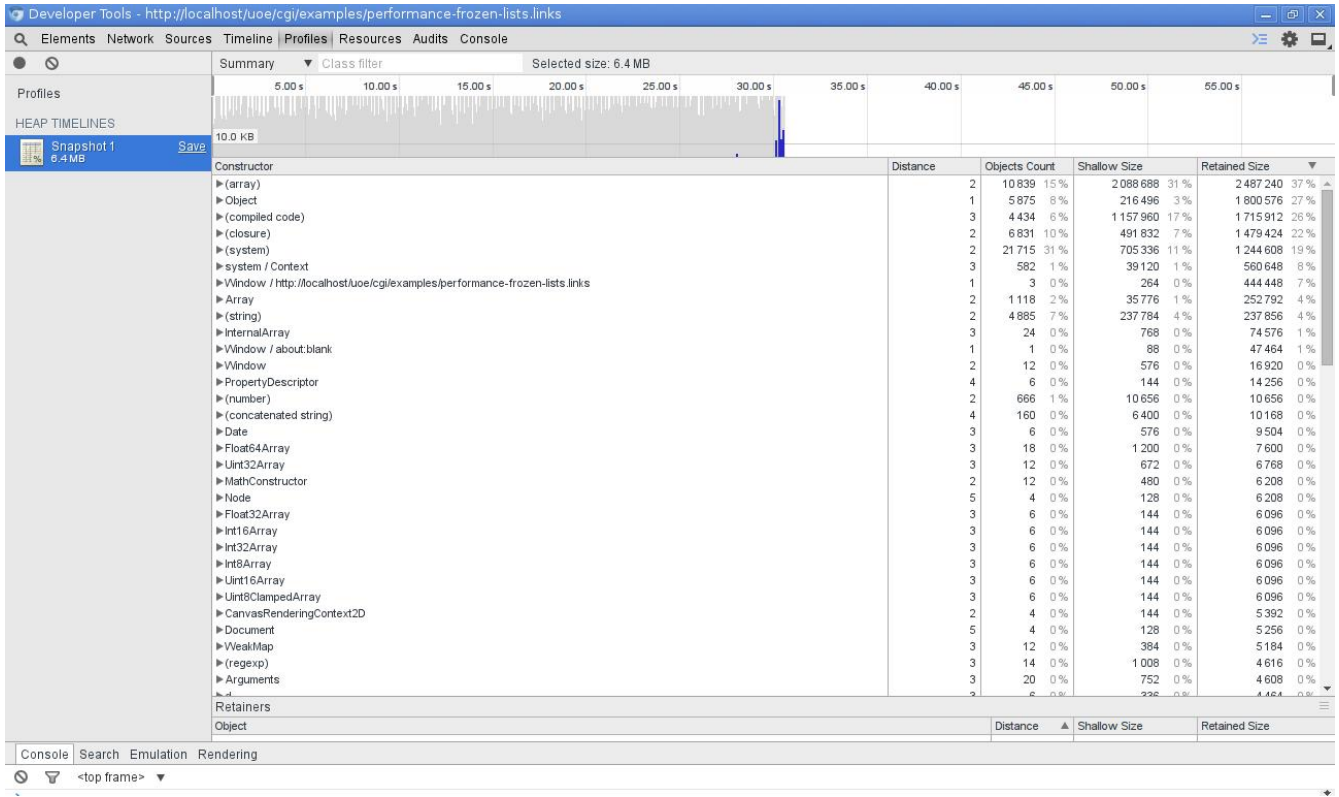
Firefox

FPS: 58.8235 highest FPS: 76.9230 granularity: 60 yieldCount: 33 double buffering: on
proper yield2 firefox



Profiling





Function	Calls	Percent	Own Time	Time	Avg	Min	Max	File
_yield2	165185	13.91%	5205.393ms	573939.758ms	3.475ms	0.07ms	77.147ms	jslib.js (line 2122)
_yieldCont	135920	11.58%	4332.607ms	489277.252ms	3.6ms	0.071ms	77.227ms	jslib.js (line 2137)
putPixel	38465	4.86%	1819.33ms	133761.883ms	3.477ms	0.177ms	46.064ms	perform...s.links (line 1990)
_lsCons	82977	4.24%	1586.679ms	1586.679ms	0.019ms	0.017ms	2.337ms	jslib.js (line 2667)
putPixel/<	38465	3.45%	1289.77ms	130851.235ms	3.402ms	0.106ms	45.986ms	perform...s.links (line 1994)
scalePoint_1687	35663	3.4%	1273.085ms	118482.167ms	3.322ms	0.107ms	46.235ms	perform...s.links (line 2106)
lsMapIgnore	24616	3.23%	1206.915ms	88030.293ms	3.576ms	0.139ms	37.123ms	perform...s.links (line 1981)
plotPoint_1738/</<	35196	3.15%	1178.661ms	117385.763ms	3.335ms	0.104ms	46.163ms	perform...s.links (line 2193)
plotPoint_1738/</</<	35196	3.13%	1170.9ms	118977.242ms	3.38ms	0.209ms	46.097ms	perform...s.links (line 2196)
plotPoint_1738	35196	3.12%	1168.553ms	115544.688ms	3.283ms	0.106ms	46.334ms	perform...s.links (line 2191)
plotPoint_1738/</</</<	35196	3.07%	1150.254ms	116714.379ms	3.316ms	0.105ms	45.918ms	perform...s.links (line 2196)
lsMapIgnore/<	23973	3.05%	1139.371ms	85225.882ms	3.555ms	0.17ms	37.017ms	perform...s.links (line 1987)
lsMapIgnore/</</<	23973	3.01%	1124.624ms	86736.398ms	3.618ms	0.201ms	37.192ms	perform...s.links (line 1987)
plotPoint_1738/<	35196	2.95%	1103.322ms	117097.326ms	3.327ms	0.138ms	46.267ms	perform...s.links (line 2193)
_jsFillRect	38465	2.92%	1091.319ms	1091.319ms	0.028ms	0.022ms	0.574ms	jslib.js (line 2539)
_lsEmpty	41804	2.1%	786.086ms	786.086ms	0.019ms	0.016ms	46.079ms	jslib.js (line 2787)
lsMapIgnore/</<	23973	2.07%	773.786ms	85397.617ms	3.562ms	0.104ms	37.26ms	perform...s.links (line 1987)
_lsFromArray	116	2%	749.553ms	1695.019ms	14.612ms	7.602ms	51.254ms	jslib.js (line 2670)
lsMap/<	14782	1.97%	736.468ms	49826.756ms	3.371ms	0.169ms	46.4ms	perform...s.links (line 1956)
lsMap	14841	1.93%	723.106ms	49896.956ms	3.362ms	0.136ms	53.874ms	perform...s.links (line 1950)
lsMap/</</<	14783	1.9%	711.75ms	50680.895ms	3.428ms	0.2ms	53.956ms	perform...s.links (line 1957)
lsMap/</</</<	14986	1.86%	694.956ms	46046.824ms	3.073ms	0.136ms	8.649ms	perform...s.links (line 1957)
_lsTail	38756	1.83%	685.066ms	685.066ms	0.018ms	0.016ms	0.533ms	islib.is (line 2715)

Conclusions

For a summary of the document see the Gist section. For sources see the footnotes scattered around the pages of this document.

Suggestions for future work

- We see that a lot of the garbage was generated because of unnecessary copying of JavaScript arrays (which are used to represent lists). The optimized linked list type, which reduces that significantly should be polished and adapted to the language.
- Specialized equality functions seem to improve the performance a bit as well, so they should replace `LINKS.eq`
- Another optimization to try out would be finding ways to reduce the frequency of context switching
- A lot of things I say here are from game development perspective, but anything relevant to that is applicable in other domains where performance is important
- For a smooth interaction with a game we should aim for a stable frame rate of at least 30 FPS (preferably 60 – standard in games)
- Good place to look for ready-made solutions are other languages, similar to Links, like Elm¹⁸ and Opa¹⁹
- A handy thing for testing and comparing the performance of various JavaScript constructs is jsPerf²⁰

18 <http://elm-lang.org/>

19 <http://opalang.org/>

20 <http://jsperf.com/>