ECE459: Programming for Performance Winter 2019

Lecture 19 — Performance Case Studies

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Making Firefox Fast

Let's look at Mike Conley's Firefox Performance Updates,

`https://mikeconley.ca/blog/2018/02/14/firefox-performance-update-1/`

- don't use CPU animating out-of-view elements
- move db init off main thread
- keep better profiling data
- parallel painting for macOS
- lazily instantiate Search Service only when first search starts
- halve size of the blocklist
- refactor to reduce main-thread IO
- don't hold all frames of animated GIFs/APNGs in memory
- eliminate an unnecessary hash table
- use more modern compiler

We can categorize most of these updates into the categories we've seen before:

- do less work
  (or do it sooner/later);
- use threads (move work off main thread);
- track performance;

Which of the updates fall into which categories?

Tab warming

We continue by examining one particular update, *tab warming*, in detail:

`https://mikeconley.ca/blog/2018/01/11/making-tab-switching-faster-in-firefox-with-tab-warming/`.

"Maybe this is my Canadian-ness showing, but I like to think of it almost like coming in from shoveling snow off of the driveway, and somebody inside has *already made hot chocolate for you*, because they knew you'd probably be cold." — Mike Conley

Consider switching tabs. Previously, Firefox would request a paint of the newly-selected tab and wait for the rendering to be available before switching the tab.

The idea is to reduce user-visible latency by predicting an imminent tab switch. How do you know that the user is about to switch tabs? When the user has a mouse, then the mouse cursor will hover over the next tab.

> Assuming a sufficiently long delay between hover and click, the tab switch should be perceived as instantaneous. If the delay was non-zero but still not long enough, we will have nonetheless shaved that time off in eventually presenting the tab to you.
>
> And in the event that we were wrong, and you weren't interested in seeing the tab, we eventually throw the uploaded layers away.

The blog post does not report performance numbers (but bug 1430160 discusses how to collect them).

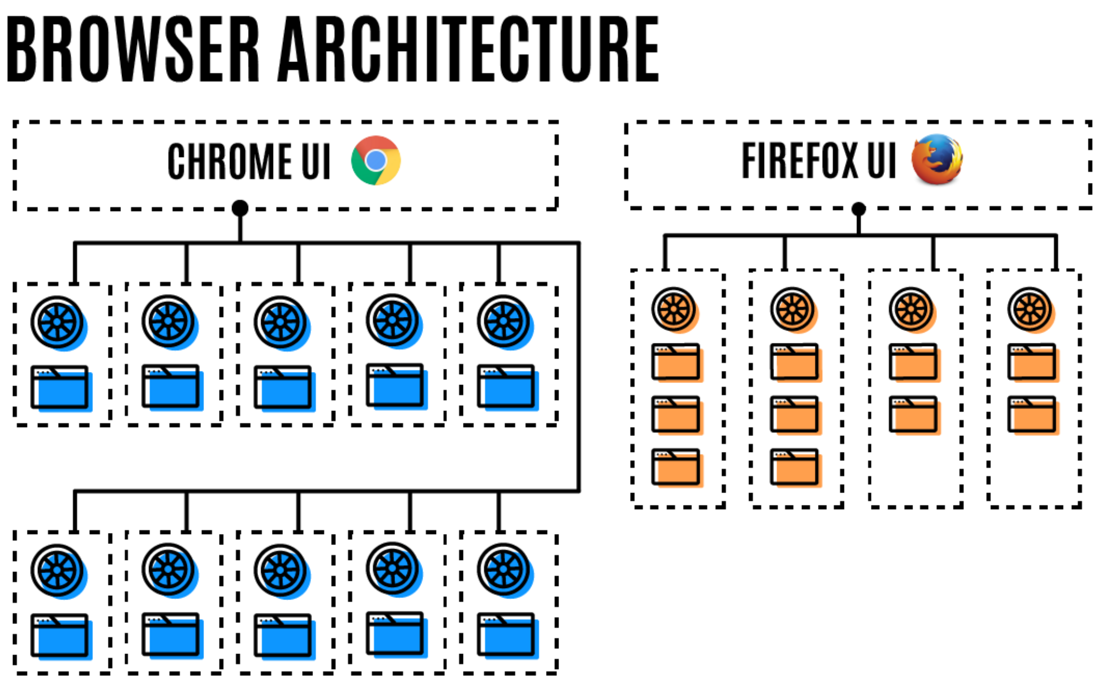
Firefox in general

Try: "about:mozilla" in Firefox. On a Quantum Flow-enabled version, you'll see

> *The Beast adopted new raiment and studied the ways of Time and Space and Light and the Flow of energy through the Universe. From its studies, the Beast fashioned new structures from oxidised metal and proclaimed their glories. And the Beast's followers rejoiced, finding renewed purpose in these teachings.*
>
> *from The Book of Mozilla, 11:14*

In 2017, Mozilla released Electrolysis (E10s[1]), which leverages multicore processors by using multiple OS-level processes. (Chrome has always done this, but Firefox attempts to also keep memory usage down[2].) Beyond internal architecture issues, handling Add-Ons (now WebExtensions) was perhaps the most challenging part of going multi-process.

Note the connection to different thread/process models. Chrome is one-process-per-tab, while Firefox multiplexes tabs across the 4 content processes ("hardware threads", by analogy). Limiting the number of tabs also limits the memory consumption of the browser: we don't have arbitrary numbers of renderer state.



Source: Ryan Pollock, "The search for the Goldilocks browser and why Firefox might be 'just right' for you", `https://medium.com/mozilla-tech/the-search-for-the-goldilocks-browser-and-why-firefox-may-be-just-right-for-you-1f520506aa35`

As a crude summary, Electrolysis works on splitting across processes while the newer Quantum Flow leverages multithreading and other improvements. Quantum Flow uses the Rust programming language and its "fearless concurrency" (in Rust-speak). Rust should probably be part of a future revision of the ECE 459 curriculum. But we'll focus on Firefox here.

[1] `https://blog.mozilla.org/blog/2017/06/13/faster-better-firefox/`

[2] `https://medium.com/mozilla-tech/the-search-for-the-goldilocks-browser-and-why-firefox-may-be-just-right-for-you-1f520506aa`

Quantum Flow

Here's a retrospective of the Quantum Flow project:

`https://ehsanakhgari.org/blog/2017-09-21/quantum-flow-engineering-newsletter-25`

To sum up, they formed a small term and did the following.

1. Measure slowness: gather information, instrument Firefox, collect profiling data and measurements. Prioritize issues.
2. Gather help: convince other teams to pitch in with perf improvements. Examples: front-end team (reduce flushes, timers); layout team (reflow performance).
3. Fix all the things! (Or at least the most important ones).

Given the short timeline they gave themselves (6 months) and the limited resources, an important part of their work was convincing others to help. They triaged 895 bugs and fixed 369 of them. The weekly Quantum Flow Engineering Newsletter was a key motivational tool.

After the project wound down, they aimed to distribute responsibility for perf improvements across the entire project.

Firefox Telemetry

Firefox's Telemetry feature collects lots of information from Firefox users. Idea: collect data before hacking away at things. Firefox collects hundreds of gigabytes of anonymous metrics per day while browsing and makes it all available to the public. One can view this as an analogy of CPU profiling on a massively distributed context. This data is collected much less often than CPU profiling data but at a much broader scope.

`https://telemetry.mozilla.org/`

If you are running Firefox and want to see what it is collecting:

`about:telemetry`

You can view distributions of telemetry probes (in the form of histograms). You can also make your own dashboard based on Firefox Telemetry data and Mozilla has infrastructure for their developres to formulate and evaluate their own queries.

Example questions:

- Is Firefox the user's default browser? (69% yes)
- Does e10s make startup faster? (no, slower)
- Which plugins tend to freeze the browser on load? (Silverlight and Flash)

Can see evolution of data over time.

Firefox developers can propose new telemetry probes which are reviewed for data privacy[3] as well as through normal code review channels.

[3] Mozilla Data Collection Practices: `https://wiki.mozilla.org/Firefox/Data_Collection`

Pings. Firefox phones the data home using so-called "pings". Firefox sends a "main ping" every 24 hours, upon shutdown, environment change, and crash. There are other types of pings as well. Pings get sent either by Firefox or by a helper program, Pingsender, when Firefox isn't running. Presumably they are sent over the network as compressed JSON to a central server.

Here's the common ping structure:

```
{
  type: <string>, // "main", "activation", "optout", "saved-session", ...
  id: <UUID>, // a UUID that identifies this ping
  creationDate: <ISO date>, // the date the ping was generated
  version: <number>, // the version of the ping format, currently 4

  application: {
    architecture: <string>, // build architecture, e.g. x86
    buildId: <string>, // "20141126041045"
    name: <string>, // "Firefox"
    version: <string>, // "35.0"
    displayVersion: <string>, // "35.0b3"
    vendor: <string>, // "Mozilla"
    platformVersion: <string>, // "35.0"
    xpcomAbi: <string>, // e.g. "x86-msvc"
    channel: <string>, // "beta"
  },

  clientId: <UUID>, // optional
  environment: { ... }, // optional, not all pings contain the environment
  payload: { ... }, // the actual payload data for this ping type
}
```

Pings contain scalars (counts, booleans, strings) and histograms. A histogram collects bucketed data (think grade distributions). Both scalars and histograms can be keyed, e.g. how often searches happen for which search engines.

Single-Thread Performance

"Can you run faster just by trying harder?"

The performance improvements we've seen to date have been leveraging parallelism to improve throughput. Decreasing latency is trickier—it often requires domain-specific tweaks. Tab warming decreses latency but doesn't increase overall throughput.

Sometimes it's classic computer science: Quantum Flow found a place where they could cache the last element of a list to reduce time complexity for insertion from $O(n^2)$ to $O(n \log n)$.

`https://bugzilla.mozilla.org/show_bug.cgi?id=1350770`

We'll also look at a more involved example of decreasing latency today, Stream VByte [LKR18]. Even this example leverages parallelism—it uses vector instructions. But there are some sequential improvements, e.g. Stream VByte takes care to be predictable for the branch predictor.

Context. We can abstract the problem to that of storing a sequence of small integers. Such sequences are important, for instance, in the context of inverted indexes, which allow fast lookups by term, and support boolean queries which combine terms.

Here is a list of documents and some terms that they contain:

docid	terms
1	dog, cat, cow
2	cat
3	dog, goat
4	cow, cat, goat

The inverted index looks like this:

term	docs
dog	1, 3
cat	1, 2, 4
cow	1, 4
goat	3, 4

Inverted indexes contain many small integers in their lists: it is sufficient to store the delta between a doc id and its successor, and the deltas are typically small if the list of doc ids is sorted. (Going from deltas to original integers takes time logarithmic in the number of integers).

VByte is one of a number of schemes that use a variable number of bytes to store integers. This makes sense when most integers are small, and especially on today's 64-bit processors.

VByte works like this:

- x between 0 and $2^7 - 1$, e.g. $17 = 0b10001$: $0xxxxxxx$, e.g. 00010001;
- x between 2^7 and $2^{14} - 1$, e.g. $1729 = 0b11011000001$: $1xxxxxxx/0xxxxxxx$, e.g. $11000001/00001101$;
- x between 2^{14} and $2^{21} - 1$: $0xxxxxxx/1xxxxxxx/1xxxxxxx$;
- etc.

That is, the control bit, or high-order bit, is 0 if you have finished representing the integer, and 1 if more bits remain. (UTF-8 encodes the length, from 1 to 4, in high-order bits of the first byte.)

It might seem that dealing with variable-byte integers might be harder than dealing fixed-byte integers, and it is. But there are performance benefits: because we are using fewer bits, we can fit more information into our limited RAM and cache, and even get higher throughput. Storing and reading 0s isn't an effective use of resources. However, a naive algorithm to decode VByte also gives lots of branch mispredictions.

Stream VByte is a variant of VByte which works using SIMD instructions. Science is incremental, and Stream VByte builds on earlier work—masked VByte as well as VARINT-GB and VARINT-G8IU. The innovation in Stream VByte is to store the control and data streams separately.

Stream VByte's control stream uses two bits per integer to represent the size of the integer:

00	1 byte	10	3 bytes
01	2 bytes	11	4 bytes

Each decode iteration reads a byte from the control stream and 16 bytes of data from memory. It uses a lookup table over the possible values of the control stream to decide how many bytes it needs out of the 16 bytes it has read, and then uses SIMD instructions to shuffle the bits each into their own integers. Note that, unlike VByte, Stream VByte uses all 8 bits of each data byte as data.

For instance, if the control stream contains $0b1000\ 1100$, then the data stream contains the following sequence of integer sizes: $3, 1, 4, 1$. Out of the 16 bytes read, this iteration will use 9 bytes; it advances the data pointer by 9. It then uses the SIMD "shuffle" instruction to put the decoded integers from the data stream at known positions in the 128-bit SIMD register; in this case, it pads the first 3-byte integer with 1 byte, then the next 1-byte integer with 3 bytes, etc. Let's say that the input is `0xf823 e127 2524 9748 1b.. .... .... ....`. The 128-bit output is `0x00f8 23e1/0000 0027/2524 9748/0000/001b`, with the /s denoting separation between outputs. The shuffle mask is precomputed and, at execution time, read from an array.

The core of the implementation uses three SIMD instructions:

```
uint8_t C = lengthTable[control];
__m128i Data = _mm_loadu_si128 ((__m128i *) databytes);
__m128i Shuf = _mm_loadu_si128(shuffleTable[control]);
Data = _mm_shuffle_epi8(Data, Shuf);
databytes += C; control++;
```

Discussion. The paper [LKR18] includes a number of benchmark results showing how Stream VByte performs better than previous techniques on a realistic input. Let's discuss how it achieves this performance.

- control bytes are sequential: the processor can always prefetch the next control byte, because its location is predictable;
- data bytes are sequential and loaded at high throughput;
- shuffling exploits the instruction set so that it takes 1 cycle;
- control-flow is regular (executing only the tight loop which retrieves/decodes control and data; there are no conditional jumps).

We're exploiting SIMD, so this isn't quite strictly single-threaded performance. Considering branch prediction and caching issues, though, certainly improves single-threaded performance.

References

[LKR18] Daniel Lemire, Nathan Kurz, and Christoph Rupp. Stream vbyte: Faster byte-oriented integer compression. *Information Processing Letters*, 130(Supplement C):1 – 6, 2018. URL: `http://www.sciencedirect.com/science/article/pii/S0020019017301679`.