Assessing Loading Performance in Real Life with Navigation and Resource Timing

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Chances are good you've opened your browser's dev tools at some point, used the network panel (or perhaps even Lighthouse) to assess performance, and discovered opportunities for improvement. Then you've refactored code, improved performance, watched metrics improve, and congratulated yourself. A job well done!

Only you're *not* done, because a problem still remains: The tests you've performed are *synthetic*. They don't tell you how your site is performing for real users in the field.

It's not that synthetic testing is *bad*, it's that it's only a part of a much larger picture of loading performance. No matter how many synthetic testing tools you use, they'll only ever provide data from a single perspective: From whatever device and network connection the test was run. Sure, the improvements you make based on synthetic test recommendations will help all your users, but to *which degree* is something you won't understand as long as synthetic testing remains your only performance measurement strategy.

This is where Real User Monitoring (RUM) comes in. RUM relies on JavaScript APIs in the browser to gather statistics on how sites perform for *real users*. Two specific APIs measure how fast documents and resources load for users by capturing high-resolution timings which measure various phases of resource loading. These are the Network and Resource Timing APIs, and this guide will help you make sense of the data they provide.

Easy APIs to help you understand network requests in the browser

Navigation and Resource Timing overlap significantly with one another, yet they each collect metrics for different things:

- **Navigation Timing** collects performance metrics for HTML documents.
- **Resource Timing** collects performance metrics for document-dependent resources. Stuff like style sheets, scripts, images, *et cetera*.

If you don't know anything about either API, you might be tempted to brush them off as too complex or unnecessary. The truth is, it's easy to *get* data from these APIs, and that data is *critical* for measuring loading performance for actual users. The *hard* part is making sense of the data they provide, but we'll cover all that soon enough. For now, let's experiment a little in the console.

Navigation and Resource Timing (as well as other related APIs) store *performance entries* in a *performance entry buffer*. In simpler terms, that just means they store performance metrics for pages and resources into a list accessible by JavaScript. Those methods exist in the `window.performance` namespace, and they help us query this list in different ways. For now, though, let's keep it simple and stick with the `getEntriesByType` method. To start, load any page in your browser, open the console, and enter either (or both) of these commands:

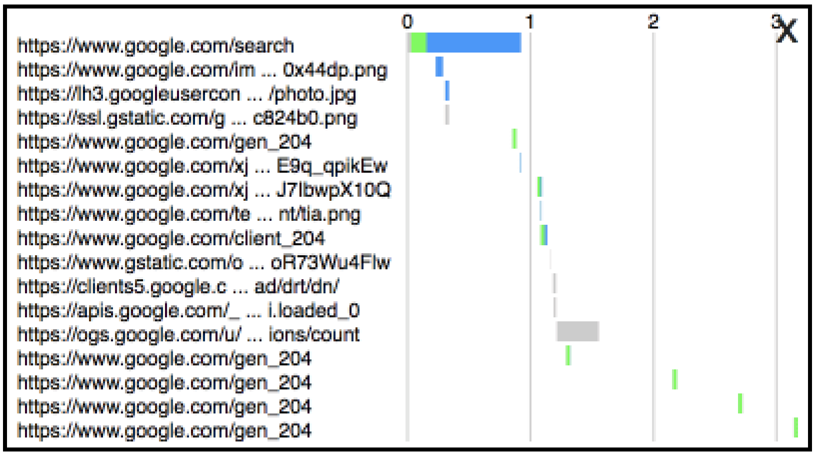
```
// Get Navigation Timing entries:
performance.getEntriesByType("navigation");

// Get Resource Timing entries:
performance.getEntriesByType("resource");
```

`getEntriesByType` accepts a string describing the type of entries you want. To get Navigation Timing entries, use "`navigation`". For Resource Timing entries, use "`resource`". After you run this, you'll see an array with an object of performance timings for the current page that looks something like this:

```
{
  "connectEnd": 152.20000001136214,
  "connectStart": 85.00000007916242,
  "decodedBodySize": 1270,
  "domComplete": 377.90000007953495,
  "domContentLoadedEventEnd": 236.4000000525266,
  "domContentLoadedEventStart": 236.4000000525266,
  "domInteractive": 236.2999999895692,
  "domainLookupEnd": 85.00000007916242,
  "domainLookupStart": 64.4000000320375,
  "duration": 377.90000007953495,
  "encodedBodySize": 606,
  "entryType": "navigation",
  "fetchStart": 61.600000015459955,
  "initiatorType": "navigation",
  "loadEventEnd": 377.90000007953495,
  "loadEventStart": 377.90000007953495,
  "name": "https://example.com/",
  "nextHopProtocol": "h2",
  "redirectCount": 0,
  "redirectEnd": 0,
  "redirectStart": 0,
  "requestStart": 152.50000008381903,
  "responseEnd": 197.80000008177012,
  "responseStart": 170.00000004190952,
  "secureConnectionStart": 105.80000001937151,
  "startTime": 0,
  "transferSize": 789,
  "type": "navigate",
  "unloadEventEnd": 0,
  "unloadEventStart": 0,
  "workerStart": 0
}
```

The density of this information can be overwhelming, but just remember one thing: Any time you've seen a waterfall chart, you're looking at a visual representation of the data these APIs provide! In fact, it's possible to generate your own visuals with this data. Good examples of this are scripts like Waterfall by Andy Davies or Performance-Bookmarklet by Michael Mrowetz.



https://www.google.com/search
https://www.google.com/im ... 0x44dp.png
https://lh3.googleusercon ... /photo.jpg
https://ssl.gstatic.com/g ... c824b0.png
https://www.google.com/gen_204
https://www.google.com/xj ... E9q_qpikEw
https://www.google.com/xj ... J7lbwpX10Q
https://www.google.com/te ... nt/tia.png
https://www.google.com/client_204
https://www.gstatic.com/o ... oR73Wu4Flw
https://clients5.google.c ... ad/drt/dn/
https://apis.google.com/_ ... i.loaded_0
https://ogs.google.com/u/ ... ions/count
https://www.google.com/gen_204
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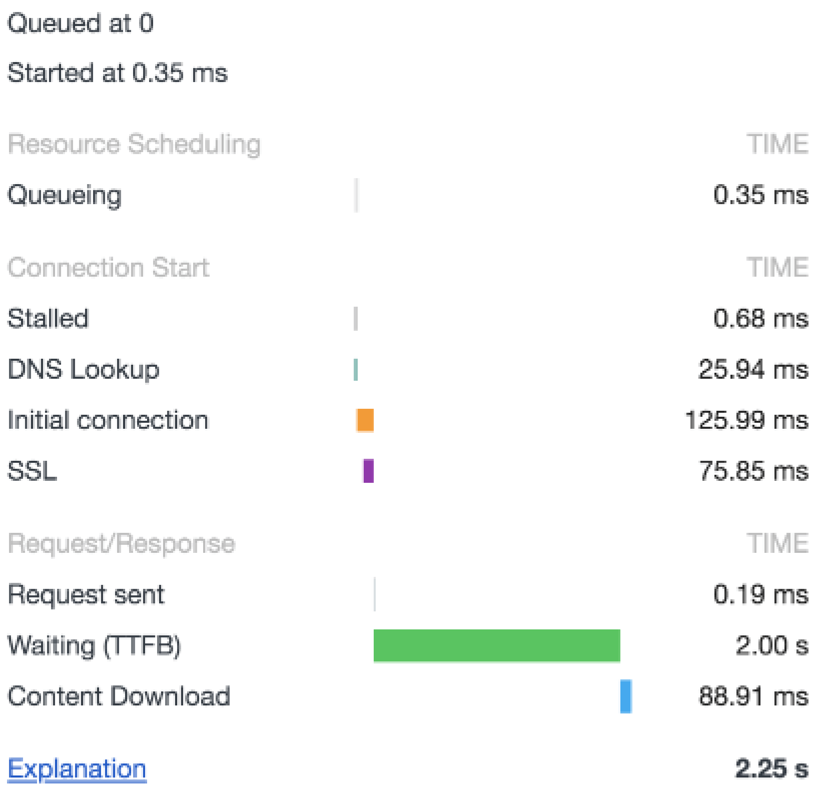
Figure 1. The Waterfall bookmarklet showing timings for a page and its resources.

Navigation and Resource Timing are APIs that help you measure how long stuff takes to load. Because these APIs are a part of JavaScript, you can use them to gather vital performance statistics from users when they visit your page. That's powerful stuff!

The life and timings of a network request

When you gather timings for page navigations and resource downloads, you're playing the role of an archaeologist in the sense that you're reconstructing the fleeting life of a network request after the fact. Sometimes it helps to visualize a concept, and where network requests are concerned, there's no better visualization tool than your browser's dev tools.



Queued at 0

Started at 0.35 ms

Resource Scheduling	TIME
Queueing	0.35 ms

Connection Start	TIME
Stalled	0.68 ms
DNS Lookup	25.94 ms
Initial connection	125.99 ms
SSL	75.85 ms

Request/Response	TIME
Request sent	0.19 ms
Waiting (TTFB)	2.00 s
Content Download	88.91 ms

Explanation **2.25 s**

Figure 2. How a network request is visualized in the network panel of Chrome's developer tools.

As you can see, this request has all the fun stuff you'd expect: DNS lookup, connection, TLS negotiation, and so on. Let's take a look together at the important (and not so important) bits in Navigation and Resource Timing, and demonstrate which properties and metrics can help you measure activity vital to application performance! Let's dig in!

Note: This guide is a bit opinionated on which metrics are most important. If you want an unopinionated bird's eye view of both APIs and the exact order metrics appear in, this Timing processing model diagram is super helpful.

DNS lookup

When a user requests a URL, the Domain Name System (DNS) is queried to translate a domain to an IP address. Depending any number of factors (notably DNS caches), this process can take significant time. Or perhaps not, but maybe it's something you want to measure anyway. Navigation and Resource Timing both expose two DNS-related metrics:

- `domainLookupStart` marks when a DNS lookup starts.
- `domainLookupEnd` marks when a DNS lookup ends.

Quite simple, really! When a network request phase is this linear, measuring its duration is as easy as subtracting the start metric from the end metric:

```
// Measuring DNS lookup time
var pageNav = performance.getEntriesByType("navigation")[0];
var dnsTime = pageNav.domainLookupEnd - pageNav.domainLookupStart;
```

Now for some bad news: You can't *always* rely on some metrics to be populated. Some properties in both APIs will be `0` under certain conditions. For example, both `domainLookupStart` and `domainLookupEnd` (and others) can be `0` for a resource served by a third party if that host doesn't set a proper `Timing-Allow-Origin` response header. We won't get into the weeds on this just yet, but we'll talk about it later on. For now, let's move on.

Connection negotiation

When a connection to a server is made, latency occurs as the client and server sort things out prior to sending resources to the client. If HTTPS is used (which is increasingly common), this process also includes TLS negotiation time. The connection phase consists of three metrics:

- `connectStart` marks when the client opens a connection to the server.
- `secureConnectionStart` marks when the client begins TLS negotiation.
- `connectEnd` marks when connection negotiation ends (including TLS time).

These are *almost* as simple as DNS metrics, but `secureConnectionStart` changes things up. You may ask "why isn't there a `secureConnectionEnd` property?" The answer is that TLS negotiation ends at the same time as `connectEnd`. In cases where HTTPS isn't used (or an HTTP connection persists), this value will be `0`, so you'll need to perform appropriate checks rather than assuming it will always be populated:

```
// Quantifying total connection time
var pageNav = performance.getEntriesByType("navigation")[0];
var connectionTime = pageNav.connectEnd - pageNav.connectStart;
var tlsTime = 0; // <-- Assume 0 by default

// Did any TLS stuff happen?
if (pageNav.secureConnectionStart > 0) {
  // Awesome! Calculate it!
  tlsTime = pageNav.connectEnd - pageNav.secureConnectionStart;
}
```

After a domain's IP is looked up and a connection is established, the *real* fun starts.

Requests and responses

When we think of what affects page speed, we're considering two factors:

- **Extrinsic factors:** This is stuff like connection latency and bandwidth. They're (mostly) out of our control as developers.
- **Intrinsic factors:** These are things we have more control over, such as server and client side architecture, and resource size.

Both types of factors affect request and response speed. Metrics related to this process are arguably most important of all, as they tell a story of how long each resource took to arrive. Both Navigation and Resource Timing describe requests and responses with these metrics:

- `fetchStart` marks when the browser starts to fetch a resource. This is distinct from a request in that it doesn't mark when the browser makes a network request for a resource, but rather when it begins checking caches (e.g., HTTP and service worker caches) to see if a network request is even necessary.
- `workerStart` marks when a request is being fetched from a service worker within a `fetch` event handler (if applicable). This will be always be `0` if a service worker isn't installed for the current page.
- `requestStart` is when the browser issues the network request.
- `responseStart` is when the first byte of the response arrives.
- **responseEnd** is when the last byte of the response arrives.

You can use these metrics to measure many aspects of loading performance. For example, you could measure resource download time while keeping cache seek times in mind:

```
// Cache seek plus response time
var pageNav = performance.getEntriesByType("navigation")[0];
var fetchTime = pageNav.responseEnd - pageNav.fetchStart;

// Service worker time plus response time
var workerTime = 0;

if (pageNav.workerStart > 0) {
  workerTime = pageNav.responseEnd - pageNav.workerStart;
}
```

You can also measure a bunch of other useful stuff as the code below demonstrates:

```
// Request plus response time (network only)
var totalTime = pageNav.responseEnd - pageNav.requestStart;

// Response time only (download)
```

```
var downloadTime = pageNav.responseEnd - pageNav.responseStart;

// Time to First Byte (TTFB)
var ttfb = pageNav.responseStart - pageNav.requestStart;
```

The other stuff

Now that we've covered the most important metrics provided by Navigation and Resource Timing, let's briefly look at some of their less consequential metrics.

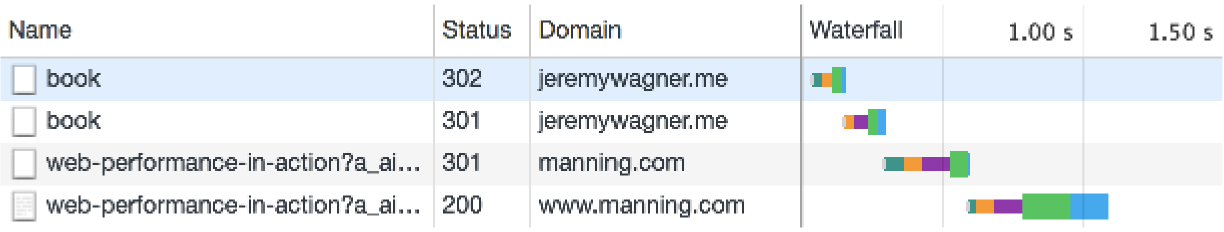
Document unloading

Unloading is when the browser does some housekeeping prior to loading a new page. This isn't a big deal in typical circumstances, but it *could* be worth quantifying if you have code (especially from third parties) running in a `unload` event handler that holds up the next page from rendering. If that describes your situation, you'll want to pay attention to the `unloadEventStart` and `unloadEventEnd` metrics.

Note: Unload metrics are exclusive to Navigation Timing.

Redirects

OK, page redirects aren't *totally* inconsequential, but they might not be something you run into very often. Still, redirects add latency to requests, so measuring them may be worth the effort.



Name	Status	Domain	Waterfall	1.00 s	1.50 s
□ book	302	jeremywagner.me			
□ book	301	jeremywagner.me			
□ web-performance-in-action?a_ai...	301	manning.com			
web-performance-in-action?a_ai...	200	www.manning.com			

Figure 3. A redirect chain shown in Chrome's developer tools.

If you're concerned about redirects, both APIs provide the `redirectStart` and `redirectEnd` metrics, which makes measuring redirect time a trivial task.

Document processing

When HTML documents load, the browser takes time to process them. Navigation Timing exposes metrics to measure this, but they aren't usually consequential unless *perhaps* you're serving huge documents. If you're interested in document processing metrics, they're `domInteractive`, `domContentLoadedEventStart`, `domContentLoadedEventEnd`, and `domComplete`.

Note: Document processing metrics are exclusive to Navigation Timing.

Loading

When a document and its resources have completely finished loading, the browser fires a `load` event. Some emphasize load time as the metric supreme, but a shift in focus has taken place to prioritize perceptual metrics (e.g., Speed Index) over load time.

Still, measuring load time may be helpful to you. `loadEventStart` and `loadEventEnd` can help you with that when it comes to documents, but it's probably easiest to just use the `duration` property.

Note: `loadEventStart` and `loadEventEnd` metrics are exclusive to Navigation Timing.

Document and resource size

The *size* of a document or resource is undoubtedly influential on loading performance. Fortunately, both APIs expose properties for quantifying resource payloads:

- `transferSize` is the *total size* of the resource including HTTP headers.
- **encodedBodySize** is the *compressed size* of the resource *excluding* HTTP headers.
- **decodedBodySize** is the *decompressed size* of the resource (again, excluding HTTP headers).

Using simple arithmetic, it's easy to figure out how much of a response consists of HTTP headers or even compression ratios:

```
// HTTP header size
var pageNav = performance.getEntriesByType("navigation")[0];
var headerSize = pageNav.transferSize - pageNav.encodedBodySize;

// Compression ratio
var compressionRatio = pageNav.decodedBodySize / pageNav.encodedBodySize;
```

You'll likely already be aware of resource size, and you don't really need an API to tell you this stuff, as the network panel in any browser's dev tools conveys this information. But the information *is* there if you need it.

Acquiring timings in application code

Now that you know some of the metrics provided by these APIs, let's cover how you can collect that data in your application code.

Other methods for manually grabbing timings

Earlier in this guide, you dabbled with `getEntriesByType`, which is great for grabbing performance entries of a specific type. There are two other related methods worth mentioning, however.

`getEntriesByName`

[`getEntriesByName`](#) gets a performance entry by its name. For Navigation and Resource Timing, this is the URL for the document or resource:

```
// Get timing data for an important hero image
var heroImageTime = performance.getEntriesByName("https://somesite.com/images/her
```

This is *super* useful if you need to get a performance entry for a single resource. It's also a better performing alternative to filtering out an array by other means.

getEntries

Unlike `getEntriesByName` and `getEntriesByType`, [`getEntries`](#) gets everything in the performance entry buffer by default:

```
// Get timing data for an important hero image
var allTheTimings = performance.getEntries();
```

But wait, there's more! `getEntries` can also serve as more verbose alternatives to `getEntriesByName` and `getEntriesByType`:

```
// Get timing data for an important hero image
var allTheTimings = performance.getEntries({
  // Get entries by name
  "name": "https://somesite.com/images/hero-image.jpg",
  // Get entries by type
  "entryType": "resource",
  // Get entries by their initiatorType value:
  "initiatorType": "img"
});
```

If `initiatorType` looks new to you, that's because I didn't cover it here. Find out more about `initiatorType` at MDN.

Listen for performance entries using PerformanceObserver

Because methods like `getEntriesByType` return arrays, you may be tempted to use a loop to work with them and say "good enough", but this approach is problematic for the following reasons:

- Loops, especially over arrays with many entries, tie up the main thread.
- Loops only capture performance entries available at the time the loop was run. Periodically polling the performance entry buffer via a timer is expensive, and competes with the renderer which can cause jank.

`PerformanceObserver` was created to address such annoyances. Using an observer pattern similar to Mutation or Intersection Observer, you can assign a callback that runs whenever new performance entries are recorded:

```
// Instantiate the performance observer
var perfObserver = new PerformanceObserver(function(list, obj) {
  // Get all the resource entries collected so far
  // (You can also use getEntriesByType/getEntriesByName here)
  var entries = list.getEntries();

  // Iterate over entries
  for (var i = 0; i < entries.length; i++) {
    // Do the work!
  }
});

// Run the observer
perfObserver.observe({
  // Polls for Navigation and Resource Timing entries
  entryTypes: ["navigation", "resource"]
});
```

This pattern can initially feel awkward if you don't have experience with observers, but it soon becomes second nature. Word to the wise: `PerformanceObserver` isn't available in all browsers Navigation and Resource Timing are available in! In fact, both Internet Explorer and Edge don't support `PerformanceObserver`, so feature check to avoid weirdness:

```
// Should we even be doing anything with perf APIs?
if ("performance" in window) {
  // OK, yes. Check PerformanceObserver support
  if ("PerformanceObserver" in window) {
    // Observe ALL the performance entries!
  } else {
    // WOMP WOMP. Find another way. Or not.
  }
}
```

With code like this, you can decide for yourself how you should collect performance timings (if at all). You may decide that collecting timings isn't worth the trouble if `PerformanceObserver` isn't available. And that's totally up to you!

The gotchas

Working with timings isn't always straightforward. As you'll recall from earlier, we brought up how some timings may be populated the way you'd expect in some circumstances, and there can be other sticky situations.

Cross-origins and the Timing-Allow-Origin header

Collecting metrics for cross-origin resources is weird, because not all performance timings are accessible for them if a `Timing-Allow-Origin` header isn't set. To find out which metrics are affected by this, check out this section of the Resource Timing spec.

If you run an application on multiple domains, or serve public assets as a third party, you should set an appropriate `Timing-Allow-Origin` header so developers can capture timings for resources hosted on them. Check out the MDN documentation for `Timing-Allow-Origin` to learn more.

Persistent connections affect timings

A persistent HTTP connection is when a connection is reused to transmit additional resources. This happens in HTTP/1 when a `Connection: Keep-Alive` header is used. When content is served over HTTP/2, a single connection is used to stream *all* resources for that origin. This behavior affects timings. It's not something you may have to explicitly check for, it's just something to be aware of when working with metrics later on.

These APIs aren't available everywhere

If working on the web has taught you anything, it's that you can't depend on APIs being available everywhere. This is equally true of Navigation and Resource Timing. The great thing about methods like `getEntriesByType` is that if they're available, they won't throw errors if they can't find anything.

This is great and all, but it can lead to a bit of confusion. In the curious case of Safari (as of version 11.2), Resource Timing is supported, but Navigation Timing isn't. That leads to situations like this:

```
// This returns stuff!
performance.getEntriesByType("resource");

// Not so much. :\
performance.getEntriesByType("navigation");
```

While this is a pain, it's not the end of the world. When you grab entries with these methods, just check if anything was returned:

```
if (performance.getEntriesByType("navigation").length > 0) {
  // Yay, we have Navigation Timing stuff!
}
```

Whether or not a browser supports these APIs, this is just a smart check to make. You should never make assumptions about what data might be available, because there are always cases where assumptions can backfire.

Phoning home

So we now know how to use these APIs and get data from them, but how do you get that data to a place where you can work with it? While this is by no means an exhaustive reference on RUM data collection, it's a place to start.

Using `navigator.sendBeacon`

You've collected performance entries, and now you're ready to send them someplace to be analyzed later. But what's the best way?

Normally we'd POST timings to an endpoint during an `unload` event, because this is when we know definitively the user is finished with the page. The problem, however, is that running code during `unload` can hold the next page up from downloading and rendering. We need to send data back in a way that won't tie up the browser while it loads a new page. For this, we have `navigator.sendBeacon`, which queues non-blocking requests with POST data to be sent asynchronously at a time of the browser's choosing:

```
window.addEventListener("unload", function() {
  // Caution: If you have a _lot_ of performance entries, don't send _everything_
  let rumData = new FormData();
  rumData.append("entries", JSON.stringify(performance.getEntries()));

  // Queue beacon request and inspect for failure
  if(!navigator.sendBeacon("/phone-home", rumData)) {
    // Recover here (XHR or fetch maybe)
  }
}, false);
```

On the other end would be some back end code that looks at the POST form data and decides what to do with it from there. How you do this depends on your application back end.

Note: `navigator.sendBeacon` only *queues* the request when called, and may not fulfill it immediately. Additionally, user agents pose restrictions on how much data may be sent, and may reject the request if that limit is exceeded.

When navigator.sendBeacon is unavailable

While `navigator.sendBeacon` is well supported, you can't use it in all browsers. Thus, some basic feature checking is necessary:

```
window.addEventListener("unload", function() {
  // Collect RUM data like before
  let rumData = new FormData();
  rumData.append("entries", JSON.stringify(performance.getEntries()));

  // Check for sendBeacon support:
  if("sendBeacon" in navigator) {
    // Beacon the requested
    if(navigator.sendBeacon(endpoint, rumData)) {
      // sendBeacon worked! We're good!
    } else {
      // sendBeacon failed! Use XHR or fetch instead
    }
  } else {
    // sendBeacon not available! Use XHR or fetch instead
  }
}, false);
```

With this approach, you'll be able to reliably transmit RUM data in most browsers. If total coverage isn't crucial, you can always opt to *not* transmit data when `navigator.sendBeacon` is unavailable.

Wrapping up

To wrap up, here's some rather opinionated, er, opinions: If you're not confident on how these timings work, don't calculate metrics on the front end and send that computed data to your back end. Store the original metrics and work with those later. This is advantageous for a number of reasons, but primarily because it's flexible. If you store the original metrics, you can always make corrections later in case of a measurement error.

Finally, you don't need to store *every* metric these APIs provide. For example, if you know for a fact you don't need to measure DOM processing time, don't feel like you *have* to store those metrics.

Of course, this guide isn't meant to be an exhaustive resource on these APIs, but rather to help you start using them with some confidence. If you want alternative perspectives on this topic, here's some additional reading:

- Navigation Timing Level 2 Spec.
- Resource Timing Level 2 Spec.
- Understanding Resource Timing.
- ResourceTiming in Practice.
- Using Navigation Timing APIs to Understand Your Webpage.

Even if you normally shy away from deeply technical reads, the official specs for Navigation and Resource Timings are easy to understand. They also break out gotchas in a hugely beneficial way. If you ever ask yourself questions like "when *is* `secureConnectionStart` `0`?", the specifications explain all the weirdness quite well.

With these APIs at your command, you'll be better equipped to understand how loading performance is experienced by real users. This means you'll be better equipped to diagnose and address performance issues in the wild, and that knowledge is truly powerful.

Special thanks to Paul Irish, Gray Norton, Addy Osmani, and Philip Walton for their valuable feedback, which significantly improved the quality of this article.

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