

# Geolocation in the Browser

## From Google Gears to Geolocation Sensors

Thomas Steiner  
Google LLC  
20354 Hamburg, Germany  
tomac@google.com

Anssi Kostiaainen  
Intel Corporation  
02160 Espoo, Finland  
anssi.kostiainen@intel.com

Marijn Krusselbrink  
Google LLC  
San Francisco, CA 94105, USA  
mek@google.com

### ABSTRACT

Geolocation is arguably one of the most powerful capabilities of smartphones and a lot of attention has been paid to native applications that make use of it. The discontinued Google Gears plugin was one of the first approaches to access exact location data on the Web as well, apart from server-side coarse location lookups based on Internet Protocol (IP) addresses; and the plugin led directly to the now widely implemented Geolocation API. The World Wide Web Consortium (W3C) Geolocation API specification defines a standard for accessing location services in the browser via JavaScript. For a long time, developers have also demanded more advanced features like background geolocation tracking and geofencing. The W3C Geolocation and the Devices and Sensors Working Groups, as well as the Web Incubator Community Group (WICG), have addressed these demands with the no longer maintained Geofencing API specification for the former, and—with now (early 2019) resumed efforts—the in-flight Geolocation Sensors specification for the latter two groups. This paper first provides an in-depth overview of the historical development of geolocation in the browser and motivates privacy decisions that were made at the time, and then gives an outlook on current and future efforts, challenges, and use cases from both a technology as well as from a privacy angle.

### CCS CONCEPTS

• Information systems → Web applications; • Security and privacy → Browser security.

### KEYWORDS

Geolocation; Geofencing; Geotracking; Permissions; Privacy

### ACM Reference Format:

Thomas Steiner, Anssi Kostiaainen, and Marijn Krusselbrink. 2019. Geolocation in the Browser: From Google Gears to Geolocation Sensors. In *Companion Proceedings of the 2019 World Wide Web Conference (WWW '19 Companion)*, May 13–17, 2019, San Francisco, CA, USA. ACM, New York, NY, USA, 6 pages. <https://doi.org/10.1145/3308560.3316538>

This paper is published under the Creative Commons Attribution-NonCommercial-NoDerivs 4.0 International (CC-BY-NC-ND 4.0) license. Authors reserve their rights to disseminate the work on their personal and corporate Web sites with the appropriate attribution.

*WWW '19 Companion*, May 13–17, 2019, San Francisco, CA, USA  
© 2019 IW3C2 (International World Wide Web Conference Committee), published under Creative Commons CC-BY-NC-ND 4.0 License.  
ACM ISBN 978-1-4503-6675-5/19/05.  
<https://doi.org/10.1145/3308560.3316538>

## 1 HISTORY OF BROWSER GEOLOCATION

Geolocation has been available to developers implicitly through the mapping of Internet Protocol (IP) addresses or address blocks to known locations. There are numerous paid subscription and free geolocation databases with varying claims of accuracy that range from country level to state or city level, sometimes including ZIP/post code level. A popular free way to obtain IP-based location data was through Google's AJAX API Loader library [2], which provided an approximate, region-level estimate of a user's location through its `google.loader.ClientLocation` property. This API did not require users to install any client-side software. Implicit geolocation access is *not* subject of the paper, however, we list it for the sake of completeness and because it still plays an important role today, for example, for IP-based regional content blocking.

### 1.1 Google Gears Geolocation API

More accurate location data is available through Wi-Fi access point or cell tower data, as well as through Global Positioning Service (GPS) data. This data is accessible to native applications, however, initially, not via Web APIs. The Google Gears browser plugin [9] for the first time exposed exact device-based geolocation data to the browser. Its Geolocation API had two JavaScript methods: `getCurrentPosition()` made a single, one-off attempt to get a position fix, while `watchPosition()` watched the user's position over time, and provided an update whenever the position changed. Both methods allowed the developer to configure which sources of location information would be used. As a simple way to get an approximate position fix with low cost in terms of both network and battery resources, Gears also kept track of the best position fix obtained from these calls and made it available as the `lastPosition` property. To a contemporary JavaScript developer who may have never used the plugin, the code in Listing 1 still looks very familiar, even more than ten years later.

```
var geo = google.gears.factory
    .create('beta.geolocation');

function updatePosition(position) {
    alert('Current lat/lon is: ' + position.latitude + ', '
        + position.longitude);
}

function handleError(positionError) {
    alert('Attempt to get location failed: ' +
        positionError.message);
}

geo.getCurrentPosition(updatePosition, handleError);
```

Listing 1: Google Gears API (2008)

From the start, user privacy was a major concern, and the plugin authors wrote in the Wiki [10]:

“It must be clear to users when an application is using the Geolocation API. We could implement one or both of the following UI elements:

(1) A separate dialog from the Gears security dialog to enable the Geolocation API. If the general-purpose dialog gave access to position data, it would be easy for users to forget they allowed access to Gears, or to fail to realize enabling Gears also exposes their position data.

(2) Some persistent UI that indicates the Geolocation API is being used. For example, there could be a bar across the bottom of the browser with an icon of a globe or map. Perhaps this UI should be ‘active’ somehow, indicating that something is happening, so that the user cannot forget it is being used.”

In the end, they decided on approach (1), which is still how location access is granted today, despite different underlying mechanics.

The similarity of the code in Listing 1 with code one would write today is no surprise. Gears implemented the at the time current editor’s draft of the w3c Geolocation specification, which some of the authors have helped to define in collaboration with Microsoft, Mozilla, and others. The goal for Gears was to advance browser capabilities and eventually make itself a relict of time, which is what has happened.

## 1.2 Mozilla Geode

Mozilla Geode [1] was an experimental add-on that appeared slightly after Gears to explore geolocation in Firefox 3 ahead of the implementation of the final API in a future product release. Geode provided an early realization of the w3c Geolocation specification [14] so that developers could begin experimenting with enabling location-aware experiences. It included a single experimental proprietary geolocation service provider called Skyhook to map Wi-Fi signals to locations, so that any computer with Wi-Fi could get accurate positioning data. An interesting historical fact is that the ultimate plan for Firefox was that service providers and geolocation methods would be pluggable [1] to provide users with as many choices and privacy options as possible, which has not happened.

## 1.3 w3c Geolocation API

The w3c Geolocation API specification [14] defines a high-level interface to location information associated only with the device hosting the implementation, such as latitude and longitude. The API itself is agnostic of the underlying location information sources, and no guarantee is given that it returns the device’s actual location. The design enables both “one-shot” position requests as well as repeated position updates, and also includes the ability to explicitly query the cached positions. As outlined above, the work is based on prior art in the industry in the form of Gears and Geode, including the work of Turner, Popescu, Sarver, Raskin, and others in the context of locationaware.org and geolocation in the Firefox browser [15].

Similar to its predecessors Google Gears and Mozilla Geode, the specification defines three methods: the `getCurrentPosition()` method asynchronously attempts to obtain the current location

of the device. If the attempt is successful, the `successCallback` must be invoked with a new `Position` object, reflecting the current location of the device. If the attempt fails, the `errorCallback` must be invoked with a new `PositionError` object, reflecting the reason for the failure. The `watchPosition()` method returns an identifier that uniquely identifies a watch operation and then asynchronously starts that watch operation. This operation must first attempt to obtain the current location of the device. Similar to the “one-shot” request, if the attempt is successful, the `successCallback` must be invoked with a new `Position` object, reflecting the current location of the device, else, it must fail as described before. The watch operation then must continue to monitor the position of the device and invoke the appropriate callback every time this position changes. The watch operation must continue until the `clearWatch()` method is called with the corresponding identifier, which immediately stops the watch operation identified by the identifier. Listing 2 shows all methods in operation (see Listing 1 for comparison). This API is almost universally supported in browsers, Figure 1 shows the support situation at the time of writing.

```
function showMap(pos) {
  // Show a map centered at
  // (pos.coords.latitude, pos.coords.longitude)
}

function scrollMap(pos) {
  // Scrolls the map so that it is centered at
  // (pos.coords.latitude, pos.coords.longitude)
}

function handleError(error) {
  // Handles the error gracefully.
}

// One-shot position request
navigator.geolocation.getCurrentPosition(showMap,
  handleError);

// Request repeated updates
var watchId = navigator.geolocation.watchPosition(
  scrollMap, handleError);

function clearPositionWatch() {
  // Cancel the updates when the user clicks a button
  navigator.geolocation.clearWatch(watchId);
}
```

Listing 2: Geolocation API

## 1.4 w3c Geofencing API

The w3c Geofencing API [12] specification defined an API that should let Web applications set up geographic boundaries around specific locations and then receive notifications when the hosting device entered or left those areas, also referred to as geofences. The Geolocation Working Group was chartered to define a secure and privacy-sensitive interface for using client-side location information in location-aware Web applications and published an update to the Geolocation API [14] specification as a Recommendation excluding the geofencing feature, which was being worked on in the context of the separate Geofencing API specification, however, the work on it did not complete. While it would be possible to implement something similar to geofencing using the Geolocation API

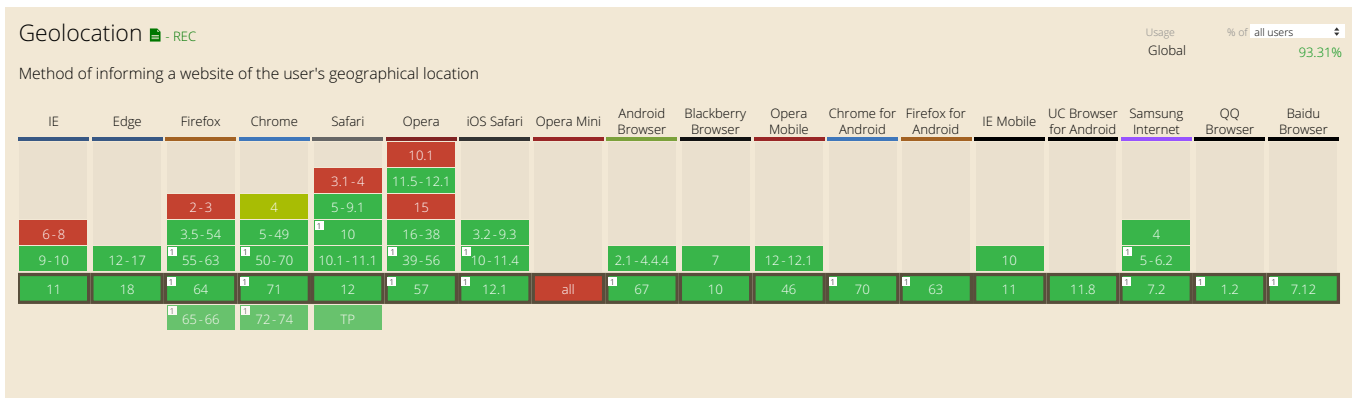


Figure 1: Browser support data for the Geolocation API (green means supported, red means not supported), data via <https://caniuse.com/#feat=geolocation>

(as long as the application is in the foreground), there were a few differences that made the proposed API look like a better choice, quoting directly from the specification [12]:

- “(1) Because of the limited API surface of the Geofencing API, user agents can implement the API in a more (power) efficient way than could be achieved by regularly checking the current geographic position with the Geolocation API.
- (2) The Geofencing API is built around Service Workers. This makes it possible for a webapp to receive notifications from the Geofencing API even after the user has closed the webapp.”

It was not generally agreed on that Service Workers were the right technology choice,<sup>1</sup> as they may be killed by the user agent at nearly any time, which means one cannot expect `watchPosition()` to keep watching for extended periods, and likewise the method `getCurrentPosition()` could only work if the position was already available, but if it has to wait for a GPS update, the Service Worker is likely to be gone by the time an answer comes back.

## 2 CURRENT GEOLOCATION EFFORTS

After having covered the significant milestones in the history of geolocation in the browser, the second part of the paper introduces some of the current efforts, challenges, and use cases in the field.

### 2.1 Background Geolocation with Wake Locks

When a device that has either of the two Geolocation API methods `watchPosition()` or `getCurrentPosition()` running goes into stand-by mode (colloquially “goes to sleep”), or when the browser window is backgrounded, location reporting stops soon thereafter. This renders certain use cases like fitness run trackers or maps

navigation that both require background geolocation entirely impossible. Wake Locks, initially introduced with the since discontinued Firefox OS [8], provided a way<sup>2</sup> to prevent the system from sleeping and to keep certain services running when the developer wanted to keep an invisible application continuing to use GPS. This could be done by requesting a `MozWakeLock` of the type “gps” and

<sup>2</sup>[https://developer.mozilla.org/en-US/docs/Archive/B2G\\_OS/API/Wake\\_Lock\\_API/Keeping\\_the\\_geolocation\\_on\\_when\\_the\\_application\\_is\\_invisible](https://developer.mozilla.org/en-US/docs/Archive/B2G_OS/API/Wake_Lock_API/Keeping_the_geolocation_on_when_the_application_is_invisible)

```

// On main page
navigator.serviceWorker
  .register('serviceworker.js')
  .then((swRegistration) => {
    let region = new CircularGeofenceRegion({
      name: 'myfence',
      latitude: 37.421999,
      longitude: -122.084015,
      radius: 1000
    });
    let options = {
      includePosition: true
    };
    swRegistration.geofencing.add(region, options)
      .then(
        // If more than just a name needs to be stored
        // with a geofence, now would be the time to
        // store this in some storage
        (geofence) => console.log(geofence.id),
        (error) => console.log(error)
      );
  });

// In serviceworker.js
self.ongeofencecenter = (event) => {
  console.log(event.geofence.id);
  console.log(event.geofence.region.name);

  // If this is not a geofence of interest anymore,
  // remove it now
  if (event.geofence.region.name !== "myfence") {
    event.waitUntil(event.geofence.remove());
  }
};

```

Listing 3: Geofencing API (conceived example)

<sup>1</sup><https://www.w3.org/2014/10/27-28-geolocation-minutes.html#day21>

```

try {
  wakeLockObj = await navigator.getWakeLock('system');
  wakeLockObj.addEventListener('activechange', () => {
    wakeLock.textContent =
      `The ${wakeLockObj.type} wake lock is ${
        wakeLockObj.active ? 'active' : 'not active'}`;
  });
} catch (err) {
  console.error('Could not obtain wake lock', err);
}

const toggleWakeLock = () => {
  if (wakeLockRequest) {
    wakeLockRequest.cancel();
    wakeLockRequest = null;
    return;
  }
  wakeLockRequest = wakeLockObj.createRequest();
};

const startTracking = () => {
  id = navigator.geolocation.watchPosition(success,
    error, opt);
};

trackButton.addEventListener('click', () => {
  toggleWakeLock();
  if (id) stopTracking();
  else startTracking();
});

```

**Listing 4: Using the Wake Lock API for background geolocation tracking**

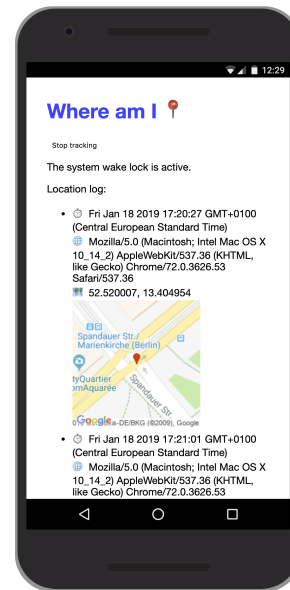
using it together with `watchPosition()`. App developers needed to be responsible and think carefully about whether they needed to keep the geolocation service on or not. The risk of claiming the lock was (and still is) that users may forget to close the app when they were done using it, which inevitably results in significantly increased battery use, apart from the privacy implications of potentially inadvertently continuing to share one’s location.

Work on the concept of Wake Locks has been resumed in the form of the w3c Wake Lock specification [3]. With the at the time of writing implemented version of the specification, Wake Locks of the type "system" (currently there is no type "gps") can be used together with `watchPosition()`. Listing 4 shows the relevant code excerpts of a Web application called “Where Am I”, depicted in Figure 2, that implements this, simulating a simple run tracker that works with the device screen off while the user runs. The accompanying app “There Am I”<sup>3</sup> can be used to visualize users.

## 2.2 Geolocation Sensor

The w3c Geolocation Sensor specification [11] extends the Sensor interface defined in the w3c Generic Sensor API [20] to in turn define the new `GeolocationSensor` interface for obtaining the geolocation of the hosting device. The Generic Sensor API is a set of interfaces that expose sensor devices to the Web platform. It consists of the base `Sensor` interface and a set of concrete sensor classes (for example `GeolocationSensor`, `AmbientLightSensor`, `Accelerometer`, *etc.*) built on top. Having a base interface simplifies the implementation and specification process for the concrete sensor classes. The core functionality is specified by the

<sup>3</sup><https://whereami.glitch.me/> and <https://thereami.glitch.me/>



**Figure 2: Web app “Where Am I” with Wake Lock for background location tracking (<https://whereami.glitch.me/>)**

base interface, and `GeolocationSensor` merely extends it with a tiny set of additional attributes and methods. The feature set of `GeolocationSensor` is similar to that of the `Geolocation` API [15], but it is surfaced through a modern API that is consistent across contemporary Sensor APIs, improves security and privacy, and is extensible. The API aims to be polyfillable<sup>4</sup> on top of the existing `Geolocation` API. As all recent APIs, instead of callbacks, `GeolocationSensor` uses promises for “one-shot” or “one-and-done” operations [6].

Unlike with the previous `Geolocation` API, the `GeolocationSensor` API does not have dedicated callbacks for “one-shot” versus continuous location requests,<sup>5</sup> but instead fires an event according to a frequency (in Hertz) that is used to calculate the requested sampling frequency for the associated platform sensor and to define the upper bound of the reporting frequency for the `GeolocationSensor` object. Listing 5 shows the API in practice, however, running it requires a polyfill, as currently there is no native implementation.

## 3 GEOLOCATION PRIVACY

Security and privacy issues for location-based services and geolocation-capable applications often revolve around designing a user interface such that users are informed about what an application is doing and have the ability to accept or decline [7]. Use cases like background geolocation or geofencing demand for a thorough re-evaluation of privacy-related questions. Similarly, some of the requirements that today we take for granted just did not exist when the `Geolocation` API was designed, like the strict requirement to be on a secure connection for using modern APIs.<sup>6</sup>

<sup>4</sup><https://github.com/w3c/sensors/blob/master/polyfills/geolocation.js>

<sup>5</sup>`GeolocationSensor` does have a dedicate static operation `read()` for “one-shot”

<sup>6</sup>Internet Explorer up to version 11 even warned its users “You are about to view pages over a secure connection” when they navigated to a site that used the HTTPS protocol.

```

// Get a new geolocation reading every second
const geo = new GeolocationSensor({frequency: 1});
geo.start();

geo.onreading = () => console.log(
  `lat: ${geo.latitude}, long: ${geo.longitude}`);

geo.onerror = event => console.error(
  event.error.name, event.error.message);

// Get a one-shot geolocation reading
GeolocationSensor.read()
  .then(geo => console.log(
    `lat: ${geo.latitude}, long: ${geo.longitude}`))
  .catch(error => console.error(error.name));

```

Listing 5: Geolocation Sensor API

### 3.1 Insecure Origin Usage of Geolocation

As the Web platform is extended to enable more useful and powerful applications, it becomes increasingly important to ensure that the features which enable those applications are enabled only in contexts which meet a minimum security level. The Secure Contexts specification [21] describes threat models for feature abuse on the Web as follows:

“Granting permissions to unauthenticated origins is, in the presence of a network attacker, equivalent to granting the permissions to any origin. The state of the Internet is such that we must indeed assume that a network attacker is present. Generally, network attackers fall into two classes: passive and active.

**1. Passive Network Attacker:** A ‘Passive Network Attacker’ is a party who is able to observe traffic flows but who lacks the ability or chooses not to modify traffic at the layers which this specification is concerned with. [...]

**2. Active Network Attacker:** An ‘Active Network Attacker’ has all the capabilities of a ‘Passive Network Attacker’ and is additionally able to modify, block or replay any data transiting the network. These capabilities are available to potential adversaries at many levels of capability, from compromised devices offering or simply participating in public wireless networks, to Internet Service Providers indirectly introducing security and privacy vulnerabilities [...], to parties with direct intent to compromise security or privacy who are able to target individual users, organizations or even entire populations.”

In a rare case of breaking backwards compatibility and after a careful risk analysis, the concepts in [21] were applied to features that had already shipped in browsers and which did not meet the—new, not present at the time—requirements. Specifically, geolocation support was removed on insecure origins, motivated by the large privacy risk for end users of even passive attackers sniffing geolocation obtained from this API.

### 3.2 Feature Policy Integration

Feature Policy [4] defines a mechanism that allows developers to selectively enable and disable use of various browser features and APIs.

The Feature Policy integration in the Generic Sensor API is used to control access to sensors data for a frame. By default the Sensor objects (and therefore the GeolocationSensor) can be created only within a main frame or same-origin subframes, thus preventing cross-origin iframes from unsanctioned reading of sensor data. This default behavior can be modified by explicitly enabling or disabling of the corresponding policy-controlled features. Listing 6 illustrates granting geolocation data access to a cross-origin iframe, meaning that now GeolocationSensor objects can be created there.

```
<iframe src="https://3rd-party.com" allow="geolocation">
```

Listing 6: Allowing an iframe to use GeolocationSensor

### 3.3 Focused Area and Visibility State

Sensor readings are only available for active documents whose origin is same origin-domain with the currently focused area document and whose visibility state is "visible". This is done in order to mitigate the risk of a skimming attack against the browsing context containing an element which has gained focus, for example when the user carries out an in-game purchase using a third party payment service from within an iframe. Similar to Subsection 2.1, these to be re-evaluated constraints currently limit use cases like fitness run trackers or maps navigation that require sensor readings in potentially non-active, non-visible documents, for example while the user chooses a music track to accompany their run or drive.

### 3.4 Permissions and Privacy Policy

Access to sensor readings are controlled by the w3c Permissions API [13]. User agents use a number of criteria to grant access to the readings. Note that while access to some sensors can be granted without prompting the user, GeolocationSensor always requires a prompt. Listing 7 shows the permissions flow that is required before any readings. In contrast, with the legacy Geolocation API, the user agent prompts the user automatically upon the first time they try to use either of watchPosition() or getCurrentPosition().

```

navigator.permissions.query({name: "geolocation"})
  .then(({state}) => {
    switch (state) {
      case "granted":
        showLocalNewsWithGeolocation();
        break;
      case "prompt":
        showButtonToEnableLocalNews();
        break;
      default:
        break; // Don't do anything if permission denied
    }
  });

```

Listing 7: Asking for permission to use GeolocationSensor

The current permission prompt has the options to allow or to block the location access request (or, for what it is worth, to ignore it by closing the dialog). Interestingly, Raskin envisioned [15] a far more detailed permissions dialog, depicted in Figure 3, which had granular levels of permitted access, for example, to limit the

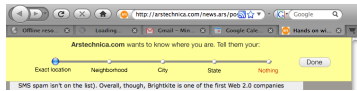


Figure 3: Aza Raskin’s security prompt mock-up [15]

granularity to city or state level. However, this was never implemented, as despite being fully investigated, it was found to be nearly impossible to implement “fuzzing” of location data [19].

With use cases like run trackers, it would additionally be of interest to limit access to background geolocation data to a given time period, for example, the duration of a one hour run. This is currently not possible, and the Permissions specification [13] is intentionally vague regarding the storage of permissions, leading to some user agents (e.g., Chrome) to persist decisions, others (e.g., mobile Safari) to ask every time, and yet others (e.g., desktop Safari or Firefox) to optionally remember them (time-limited for Safari).

A notable privacy discussion was happening between the IETF GEOPRIV and the w3c Geolocation Working Groups around the question of whether or not a privacy policy should be included in the Geolocation API itself, or rather be addressed as a set of recommendations and requirements in the specification. The Geolocation Working Group concluded<sup>7</sup> that privacy protection was better handled as part of a more generic privacy and security framework for device access. Privacy and security threats now take a significant amount of space in the Generic Sensor specification [20].

#### 4 FUTURE WORK AND CONCLUSION

Future work will happen in several areas and touch upon both technological as well as user privacy related aspects. In the following paragraphs, we present some of them, but note that especially the permission aspects reach a lot further than geolocation.

We will continue our experiments with Wake Locks [18] and how they can interact with Geolocation Sensor, with a special focus on sensor readings in non-focused and non-visible states (Subsection 3.3). Further, after having explored use cases around background geolocation and geofencing [11] in more detail, we will resume our work on Geofencing [12] and investigate integration of this feature with Geolocation Sensor [11], possibly via the extensibility mechanism defined in Service Workers [17] that makes them extensible from other specifications through a functional event by extending the `ExtendableEvent` interface.

User privacy is central to all sensor readings, and particularly to geolocation. As outlined in Subsection 1.1, from the start it was a major concern and especially with new background geolocation and geofencing use cases, it remains an issue of high importance. In [16], Russell and Nattestad have explored permission dialog abuse, annoyance, and fatigue of users; and according to their opinion (which we support), “today’s permissions model and API surface area should be heavily revised [...] to enable more flexible permission policies” in a more uniform Permissions API [13]. Some ideas include supporting both time-limited as well as one-off requests and permission grants, but also extending Web Application Manifest [5] to allow sites to identify to the runtime a maximum set of permissions, and turn down permission requests not explicitly

<sup>7</sup><https://www.ietf.org/lib/dt/documents/LIAISON/file727.txt>

included in the Web Application Manifest, with installability [5] of Web apps potentially considered an additional trust factor.

Concluding, in this paper we have first provided an overview of the historical development of geolocation in the browser, and given an outlook on current and future efforts, challenges, and use cases in the field. The importance of user privacy is ever-increasing, and in our work on geolocation, background geolocation, and geofencing, we keep privacy as a top priority. While many privacy concerns such as unsanctioned third-party access and fingerprinting can now be mitigated by technical measures, we continue to work with the privacy research community to ensure the Web remains a both capable and safe platform today and in the future by carefully assessing every new proposed feature for possible privacy threats.

#### ACKNOWLEDGEMENTS

We are thankful to *Doug Turner* for his invaluable help with getting the historical facts right and to *Alex Russell* for reviewing the paper.

#### REFERENCES

- [1] Chris Beard. 2018. *Introducing Geode*. Blog Post. Mozilla Labs, <https://blog.mozilla.org/labs/2008/10/introducing-geode/>.
- [2] Steve Block. 2008. *Two new ways to location-enable your web apps*. Blog Post. Google Developers, <https://developers.googleblog.com/2008/08/two-new-ways-to-location-enable-your.html>.
- [3] Ilya Bogdanovich, Andrey Logvinov, and Marcos Cáceres. 2017. *Wake Lock API*. Candidate Recommendation. w3c, <https://www.w3.org/TR/wake-lock/>.
- [4] Ian Clelland. 2019. *Feature Policy*. Editor’s Draft. w3c, <https://w3c.github.io/webappsec-feature-policy/>.
- [5] Marcos Cáceres, Kenneth Rohde Christiansen, Mounir Lamouri, Anssi Kostiainen, Rob Dolin, and Matt Giuca. 2018. *Web App Manifest, Living Document*. Working Draft. w3c, <https://www.w3.org/TR/appmanifest/>.
- [6] Domenic Denicola. 2018. *Writing Promise-Using Specifications, Finding of the w3c TAG, 9 November 2018*. Technical Report. w3c, <https://www.w3.org/2001/tag/doc/promises-guide/>.
- [7] Nick Doty and Erik Wilde. 2010. *Geolocation Privacy and Application Platforms*. In *Proceedings of the 3rd ACM SIGSPATIAL International Workshop on Security and Privacy in GIS and LBS (SPRINGL ’10)*. ACM, New York, NY, USA, 65–69. <https://doi.org/10.1145/1868470.1868485>
- [8] Ben Francis. 2017. *The Story of Firefox OS*. Blog Post. Medium.com, <https://medium.com/@bfrancis/the-story-of-firefox-os-cb5bf796e8fb>.
- [9] Google Gears. 2008. *Geolocation API*. Documentation. Google, [https://web.archive.org/web/20080902073745/http://code.google.com:80/apis/gears/api\\_geolocation.html](https://web.archive.org/web/20080902073745/http://code.google.com:80/apis/gears/api_geolocation.html).
- [10] Google Gears. 2008. *GeolocationAPI*. Wiki. Google, <https://web.archive.org/web/20080901235406/http://code.google.com:80/p/gears/wiki/GeolocationAPI>.
- [11] Anssi Kostiainen, Thomas Steiner, and Marijn Kruisselbrink. 2018. *Geolocation Sensor*. Working Draft. w3c, <https://www.w3.org/TR/geolocation-sensor/>.
- [12] Marijn Kruisselbrink. 2017. *Geofencing API*. Working Group Note. w3c, <https://www.w3.org/TR/geofencing/>.
- [13] Mounir Lamouri, Marcos Cáceres, and Jeffrey Yasskin. 2017. *Permissions*. Working Draft. w3c, <https://www.w3.org/TR/permissions/>.
- [14] Andrei Popescu. 2016. *Geolocation API Specification 2nd Edition*. Recommendation. w3c, <https://www.w3.org/TR/geolocation-API/>.
- [15] Aza Raskin. 2010. *Geolocation in Firefox and Beyond*. Blog Post. Aza on Design, <http://www.azarask.in/blog/post/geolocation-in-firefox-and-beyond/>.
- [16] Alex Russell and Thomas Nattestad. 2018. *Permissions Workshop*. Position Paper. w3c, <https://www.w3.org/Privacy/permissions-ws-2018/papers/thomas-nattestad.pdf>.
- [17] Alex Russell, Jungkee Song, Jake Archibald, and Marijn Kruisselbrink. 2017. *Service Workers 1*. Working Draft. w3c, <https://www.w3.org/TR/service-workers/>.
- [18] Thomas Steiner. 2018. *Experimenting with the Wake Lock API*. Blog Post. Medium.com, <https://medium.com/dev-channel/experimenting-with-the-wake-lock-api-b6f42e0a089f>.
- [19] Martin Thomson. 2011. *Obscuring Location*. Internet Draft, GEOPRIV. IETF, <https://tools.ietf.org/id/draft-thomson-geopriv-location-obscuring-03.html>.
- [20] Rick Waldron, Mikhail Pozdnyakov, and Alexander Shalamov. 2018. *Generic Sensor API*. Candidate Recommendation. w3c, <https://www.w3.org/TR/generic-sensor/>.
- [21] Mike West. 2016. *Secure Contexts*. Candidate Recommendation. w3c, <https://www.w3.org/TR/secure-contexts/>.