The current Web API landscape does not scale well: every API requires its own hardcoded clients in an unusually short-lived, tightly coupled relationship of highly subjective quality. This directly leads to inflated development costs, and prevents the design of a more intelligent generation of clients that provide cross-API compatibility. We introduce 5 principles to establish an ecosystem in which Web APIs consist of modular interface features with shared semantics, whose implementations can be reused by clients and servers across domains and over time. Web APIs and their features should be measured for effectiveness in a task-driven way. This enables an objective and quantifiable discourse on the appropriateness of a certain interface design for certain scenarios, and shifts the focus from creating interfaces for the short term to empowering clients in the long term.

No two websites are the same—yet people navigate around the Web remarkably well. We owe part of our capabilities to the reuse of well-known interaction patterns across the majority of websites. Usability expert Jakob Nielsen asserted that “users spend most of their time on other websites”, so interaction designers and information architects should structure their interactions using shared principles, only inventing new patterns when strictly necessary. Some patterns are self-documenting, such as a light-colored box with magnifying glass to perform searches; others rely on convention and reoccurrence, such as repurposing the top logo as a home button or autocompleting keywords in a text field. Components to build such interfaces are reusable through popular platforms like jQuery, Angular, and React. Crucially, human Web interactions are measurable: the effectiveness of each pattern, and of websites as a whole, can be assessed and optimized through in-page analytics scripts that track users’ behavior. An effective interaction design enables users to find information and purchase goods with a minimal amount of thought across websites.

Automated clients, in contrast, are limited to the servers for which they were preprogrammed, and cannot use other Web interfaces—not even those with similar functionality. Obviously, computer programs possess less advanced coping mechanisms compared with humans. But more importantly, Web APIs—the machine equivalent of websites—do not provide reusable patterns. Such circumstances are difficult even for humans, so it is remarkable that we deprive the far less capable automated clients of such support. Moreover, even if architects were to consider interface reuse, identifying the most effective patterns would be troublesome, as API design has no equivalent of Web analytics to measure an API’s effectiveness.

As an example, observe the human and machine sides of Facebook and Twitter. Their user interfaces for posting a status update with a picture are identical: a white textbox with an encourag
ing question and a camera icon. Measurements from millions of users have proven this interface's effectiveness, and if you can use one site, you can use all others like them. Their machine interfaces, however, differ substantially: posting on Facebook happens with one request, whereas Twitter requires an additional operation to upload pictures. Moreover, the HTTP requests and JSON responses are structurally dissimilar. Clients designed for one interface cannot work with the other, despite the use cases being nearly identical. Which of these interaction designs is "better", what does that mean, and how do we quantify that? Can this knowledge help us improve the design of other APIs? In order to evolve Web API design from an art into a discipline with measurable outcomes, we propose an ecosystem of reusable interaction patterns similar to those on the human Web, and a task-driven method of measuring those.

The need for reuse

The current lack of interface reuse within the Web API landscape hinders the flexibility of clients and inflates development costs, since many specific clients are needed instead of a few generic ones. Simple clients that interact with one API are expensive, since existing code from other APIs cannot be reused. More complex clients that integrate with multiple APIs become progressively more expensive, since each API requires its own code—even if it has similar functionality as already-integrated APIs. Building a new generation of “intelligent” clients, which interact with servers they have not encountered before—as humans do—is impossible. While API-specific frameworks and description-based code generators help reduce development costs, these contribute to the compatibility problem rather than to its solution, as they facilitate the status quo by translating HTTP interfaces into language-specific libraries. Even worse, such tools further inflate the costs of producing and maintaining APIs, which is already expensive due to non-existent application-level reuse. While protocol frameworks and guidance in the form of best practices exist, the interfaces themselves are built from scratch, for lack of drop-in interface components.

Literature extensively discusses software reuse, defined as “the use of engineering knowledge or artifacts from existing systems to build new ones” [1] and “the systematic practice of developing software from a stock of building blocks” [2]. Reuse within smaller groups is regarded as easier than within large environments [1], and the design of reusable components typically costs more [3]. On the Web, building blocks with a well-defined interface [4] can be exposed as Web services [5]. However, in those cases, reuse is mostly considered from the viewpoint of the application. There is no shortage of such application-centric reuse on the Web, as this is the very purpose for which Web APIs and clients are designed. Indeed, many different clients interact with the same Web APIs, which encapsulate functionality in the traditional sense of reuse [4,2]. Servers hosting similar APIs, in contrast, tend not to reuse.
However, the problem at hand is not *implementation reuse* across servers, which would reduce diversity, but rather the lack of *interface reuse*, which prevents clients of one Web API from interacting with functionally similar ones. The Web actually benefits when multiple providers offer custom implementations, as it creates choice. Some APIs come with their own client-side framework, which even provides code reuse for clients of those *individual* APIs. Yet the issue we address is the compatibility of clients, and reuse of their implementations, with *different* Web APIs. This can be achieved through (partial) reuse of the *interface*. Earlier literature did not consider this, since the Web’s scale of many servers with similar building blocks is unprecedented. Discussing reuse thus requires distinguishing the *interface* aspect from its *implementation*, even though the term “Web API” can refer to both.

**Bottom-up instead of top-down**

Interface reuse is absent because current Web APIs are constructed and consumed like monoliths. Clients and their developers view APIs in a *top-down* manner (Figure 1): they approach the API as a single custom entity with its own governing rules. Even though the API likely consists of different operations, those are specific to the API. Furthermore, while several APIs incorporate similar or identical functionality, such as searching or uploading, these operations have different interfaces and implementations. This sharply contrasts with interfaces on the human Web: we recognize smaller interface components across websites (search bars, share buttons, address forms, . . .), and these parts guide us through the entire functionality of the interface.

![Figure 1](image)

Figure 1: Instead of the current top-down Web APIs, we propose a bottom-up interface structure.
Therefore, we propose to build Web interfaces for machines similarly in a bottom-up manner, by composing them of reusable features (Figure 1). A feature is an independent part of an interface that identifies, describes, and affords a certain kind of interaction across Web APIs. All features of a certain kind adopt a common interface to maximize interoperability. Examples of such features include interfaces to perform full-text search, autocompletion, file uploads, status updates, etc. Developers program against such generic interface features rather than against a specific API, which makes clients compatible with any API that contains these features. As an additional benefit, clients and servers can reuse feature implementations.

**Interface principles**

In order to unlock the benefits of bottom-up interfaces, we propose 5 interface design principles.

**Principle 1:** Web APIs consist of features that implement a common interface.

This principle breaks up a monolithic custom interface into clearly delineated interface parts that can be reused across different APIs. This contrasts with microservices [6], which are highly specific and replaceable implementations, possibly written in different languages and/or deployed on multiple platforms. Instead, features focus on a reusable, generic interface, and are grouped together to form an API, which is usually written in a single language and hosted on a single machine or cluster. Features can be compared to visual components that coexist on the same page but are interacted with independently, such as a search form, upload form, or order button.

**Principle 2:** Web APIs partition their interface to maximize feature reuse.

While each Web API is different, similar functionality appears in many of them—to a much higher degree than with operating system or software framework APIs. This second principle therefore encourages architects to increase modularity, such that similar features can be reused without modification elsewhere. Clients of specific features can be reused and/or abstracted into frameworks, and they are unaffected by changes in other API features, increasing temporal compatibility. Some APIs might still require custom features; this is acceptable, since the size of such features can be minimized by exposing more common functionality (such as search) through reusable features instead.

Following this principle, the Facebook and Twitter interfaces to post a status update with a picture would consist of two features: upload file and set status. Reusability now extends to several use cases, such as third-party APIs that provide file uploading, or social networks with text-only statuses. Clients developed against the set status feature are compatible with other social network APIs (pending other concerns such as authentication, which in turn can be provided as features).

**Principle 3:** Web API responses advertise the presence of each relevant feature.

By explicitly including or linking to the list of supported features in each response, clients
Principle 4: Each feature describes its own invocation and functionality.

Instead of indicating a feature’s presence with a signature or uniform identifier, the response should contain a hypermedia control or equivalent that explains simultaneously what the feature does and how it is accessed. On the human Web, forms detail what function they perform (for instance, through field labels or descriptive text), and shape user input into an HTTP request. Similarly, machine clients of features do not need a hard-coded template of HTTP requests, which can differ between feature implementations across APIs. For example, the home resources of Facebook and Twitter can contain their own hypermedia control for status update, explaining how to construct an HTTP request from them (invocation) through a list of standardized field identifiers that have a certain effect (functionality).

If the functionality is self-describing in sufficient depth with agreed-on primitives, more intelligent clients might be able to make use of API features for which they have not been specifically pre-programmed. When formal semantics are employed, clients can reason about equivalence or subsumption of features, enabling highly precise functional matches. For example, clients could recognize variants of search or upload functionality, such as posting a photo with specific dimensions rather than any file.

Principle 5: The impact a feature on a Web API should be measured across implementations.

This final principle ensures that the properties of features become quantified, such that API designers understand the impact of adding them. Importantly, we focus on measuring the interface rather than a single implementation, in order to understand its inherent trade-offs. For example, text search can be provided through different interfaces, such as keyword-based or regular-expression-based. The latter is clearly more expressive, but likely also more expensive for the server, independently of any implementation. Similarly, even though separate upload and status features might increase modularity, this might come at a performance penalty. Choosing between one or the other should be an informed decision instead of guesswork: measurable evidence about features should therefore steer the API design decision process.
The above principles improve the compatibility of clients, because they bind to reusable parts instead of to entire APIs. Clients gain the ability to interact with APIs for which they were not specifically programmed, because of the increased granularity provided by features and their explicit description in responses. In that sense, feature-based APIs are a granular way of implementing the *hypermedia constraint* of the REST architectural style [7], which aims to broaden client/server compatibility. Server development is simplified because API design decisions become more localized and benefit from the design of existing APIs and features. Both client and interface-related server code is reusable across APIs. Features reduce the need for API-specific client frameworks or descriptions and associated auto-generated code stubs with a limited lifespan.

**Toward an ecosystem**

To experience the benefits of bottom-up Web APIs, different parties need to create and maintain an ecosystem of features. Starting from scratch is not necessary, as preliminary API features can be recognized in earlier initiatives. For example, OpenSearch is a feature to automatically search websites’ contents, and can be advertised inside of responses. Atom allows viewing, editing, and creating lists of items, and integrates well with other features. We can easily imagine OpenSearch and Atom being reused to search or navigate a set of tweets or status updates.

A functional ecosystem, however, is based on a shared understanding, not only of the features themselves but also the primitives they are built of. We need solutions to advertise the interface of features and to describe their functionality. In essence, we require the equivalent of hypermedia controls from HTML (input fields, buttons, forms, …) and their usage instructions (labels, legends, …). Various initiatives for machine-interpretable hypermedia controls exist, each with varying degrees of machine-accessibility. Importantly, self-descriptiveness is a *relative* rather than an absolute notion: a feature is only self-explanatory to the extent its recipient understands the atoms it consists of. We therefore have to agree on a set of primitives shared by all actors. Possibilities include a common vocabulary such as Schema.org or more decentralized solutions relying on Linked Data.

Within a feature ecosystem, documentation, implementations, and frameworks for certain features can be shared, as well as metrics on their usage and adoption. Following the fifth principle, measurements of the impact of features can be published and discussed, providing measurable evidence to guide API designers through the decision whether or not to include certain features. Such impact evaluations should be performed in the context of specific tasks, where different combinations of feature sets are compared from the viewpoints of clients, servers, and possible intermediaries such as caches.
Potential obstacles

The cost of reuse is well-documented in literature [3]. However, calculations of that cost typically center on the question whether a specific use case benefits from reuse. In the case of Web APIs, that decision has already been made: their main goal is reuse of server-side functionality by clients. As such, the associated expenses occur in any case. Given that different Web APIs will provide reusable functionality anyway, our question is rather to what extent APIs with similar functionality can partially reuse interfaces. This will likely also come at some cost. A community will need to reach consensus on the definition and design of reusable features, perhaps through standardization. API designers will need to identify the features that are most suitable for their API. Yet at the same time, this type of reuse also cuts costs, because client frameworks and implementations can interact with different servers.

Incentives for client and server developers are an important issue. Convincing major players to reuse API features, when they have the power to push any API they want, might be a difficult task. Therefore, we might want to approach adoption from a bottom-up perspective as well and focus on small to medium players. For them, reusing API features means making their API compatible with existing clients. For example, consider a local restaurant that aims to provide a reservation Web API. The likelihood an adequate client exists increases when other restaurants reuse a table reservation feature. In absence of reuse, and despite hosting their own website for humans, restaurants now resort to paid centralized APIs instead, which come with API-specific machine clients.

Case study

To understand the mechanisms behind features, we apply the five principles to the use case of querying Linked Data on the Web. A server hosts a dataset, modeled as RDF triples, and the goal of clients is to evaluate complex queries over it. Queries are expressed in the SPARQL query language, specifying patterns and joins over triples, as well as constraints such as textual and numerical filters. This task can be accomplished with the SPARQL protocol, a standardized Web API, but we will address it with a feature-based approach instead.

Feature design

Following Principle 1, an API is a collection of features, which Principle 2 tells us to reuse. We should therefore consider how to map the evaluation of SPARQL queries into modular blocks, checking which ones exist. For instance, OpenSearch might address the text search part of queries. However, the core elements of SPARQL queries are triple patterns, for which no feature exists. Hence, the Triple Pattern Fragments (TPF) [8] feature was designed. Clients send triple pattern subqueries to the API, decomposing each SPARQL query they receive, and combining results locally.
The design of the feature minimizes the complexity for the server, since triple patterns are easier to evaluate than SPARQL queries. However, we emphasize that this is not the only option: other choices will have a different impact on the client and server. Applying the principles thus does not necessarily increase client complexity.

Principle 3 specifies to indicate a feature’s presence, and Principle 4 mandates a description of invocation and functionality. TPF addresses both together by providing a recognizable hypermedia control (presence), with fields for each of the three triple pattern components (invocation), explaining that their input filters the dataset (functionality). This way, clients can discover that they should decompose SPARQL queries into triple patterns and place their components in the fields to create HTTP requests.

Evaluation

Finally, Principle 5 involves measuring features to understand their impact. A priori, we know that clients of the TPF feature send out many more requests than clients of the SPARQL protocol. However, the SPARQL protocol performs a more complex operation. API designers thus have to decide which feature is more adequate: one with a high number of simple requests or one with a low number of complex requests. A discussion of qualitative arguments cannot yield conclusive evidence to prefer one option over another. Even if it did, it would not reveal how much better a certain feature performs, and in what cases.

Measurements  Previous work [8] introduced a controlled task, involving 60 client machines running 4 single-threaded client instances each, 1 HTTP cache, and 1 server with an API consisting of either a SPARQL feature or a TPF feature. Clients were given varying sets of benchmark queries against a 100 million-triple dataset on the server, fronted by the HTTP cache. During execution, performance, bandwidth, and CPU usage were measured, using different feature implementations to avoid bias. Figure 2 shows the evolution of measurements from 1 to 240 clients.

Results  Clearly, the results compare the interfaces of features rather than their concrete implementations: both SPARQL implementations react similarly, but their behavior contrasts sharply with the TPF feature. SPARQL protocol throughput is higher, but decreases sharply with increasing client numbers, which affect the TPF feature far less. The bandwidth in the second graph is higher for the TPF feature. However, most of that is handled by the cache, indicating that TPF feature clients reuse API resources at a much higher rate. The design of the TPF feature thus positively affects resource cacheability. For the SPARQL feature, server CPU load is high and client load low, and vice versa for the TPF feature. The throughput of the SPARQL feature thus comes at a substantial server cost, whereas the caching benefits and scaling behavior of the TPF feature translate to elevated client-side processing. Knowledge of this trade-off is important when equipping servers with an API.
Figure 2: Comparing the SPARQL protocol feature (two implementations) to the Triple Pattern Fragments API feature (one implementation). X-axes are logarithmic, as is the y-axis in the first graph.
**Extensions** Both the SPARQL and TPF features can be complemented with an OpenSearch-like feature, to speed up queries with text-based filters. Other features can provide additional metadata to improving join performance. Because of the feature-based approach, clients that only support TPF can still use Web APIs that combine TPF with other features.

**Meta-discussion** Measuring API features, as opposed to comparing them through argumentative discourse, yields important insights. The conclusion is nuanced, as no feature is necessarily “the best”. The right choice depends on external constraints: available server capacity, budget, expected number of clients, whether high performance is more important than consistent performance. The analysis reminds us that API impact is not limited to client or server. Caching is perhaps underestimated during the design of Web APIs because quantitative analyses like the one above are not routinely applied.

Task-based evaluations can guide API decisions in other contexts. For instance, Facebook recently introduced its query-based GraphQL interface. Other providers should be able to decide whether GraphQL or a less expressive feature design fits their use case better. As a caveat, results of such analyses published as part of an ecosystem must be generalized carefully and interpreted in the proper context. For instance, the throughput realized by simple features can strongly improve in relation to more complex features when query execution over multiple Web APIs is considered.

**Conclusions and future directions**

Despite the substantial increase in machine-to-machine interactions, automated clients are still treated as secondary Web citizens. Web APIs lack recognizable interface patterns, even though machines need these more than humans for interacting with different servers. Hence, we have proposed a feature-based method to construct the interface of Web APIs, favoring reuse over reinvention, analogous to component-driven interaction design on the human Web. We have emphasized a quantifiable approach to arrive at an ecosystem of reusable features with a well-understood impact on Web APIs.

Such an ecosystem changes Web server and client development in three major ways. First, clients gain the ability to interact with multiple similar Web APIs rather than only one. This reduces development costs because client-side code and frameworks can be reused across different Web APIs and over time. Server interface design is reduced to selecting appropriate patterns based on functional and non-functional characteristics. Second, an ecosystem broadens an end user’s choice from specific client/API combinations to a variety of API-independent clients for a given task. For example, instead of choosing between a certain Facebook or Twitter client, users could opt for a status update application that matches their usage pattern and interfaces with any social
network. This sets the stage for even more generic clients that are not explicitly preprogrammed for certain interactions but interact with self-describing features. Third, an ecosystem of reusable features contributes to measurable improvements of machine-to-machine interfaces. This elevates Web API design from a best practices-based craft to a measurable discipline, where interface decisions are guided by measurable evidence.

Furthermore, a feature-based design opens up new possibilities to scale individual APIs. We have so far discussed scalability as the compatibility of clients across servers and time. However, since bottom-up Web APIs explicitly indicate the availability of features, we can enable and disable these at runtime. For example, during peak hours, server load can be reduced by selectively switching off features. Alternatively, certain features could be activated depending on clients’ subscription plans. More complex query functionality (with higher server load) can be reserved for paying customers. More simple query operations that achieve the same result (with higher client investment) can be available freely or at a lower price.

While this article outlines the principles for an ecosystem and discusses several examples, we purposely do not endorse a specific approach or methodology. Promising technologies and conventions are under development. For example, Schema.org provides an ontology to describe actions such as product orders and restaurant reservations. Together with generic machine-interpretable hypermedia controls, these could provide some of the primitives.

What an ecosystem needs foremost is a community of adopters to foster it. This partly involves creating the right incentives, but definitely also encouraging an appropriate mindset. It is tempting to create customized Web APIs, certainly in the presence of economic stimuli to favor proprietary client/server solutions that are incompatible with related products. Reuse, at its core, is about opening up development, dissolving borders, and realizing cross-fertilization between different parties. This challenges our current conception about Web APIs and the business models created around them. It forces us to think on a longer temporal scale, perhaps even further ahead in the future than the typical lifetime of many Web APIs. This will require an active community that maintains a repository of features in the long term.

Our plea for reuse, however, is only a means to an end: the ultimate goal is empowering automated clients on the Web. After all, the major innovation of the Web is its uniform interface—the Web browser—to different providers of information and services. Despite a uniform protocol, machine clients remain confined to case-specific interactions, much like we have been before the Web. The logical next step is the realization of a similar independence for machine clients, so that they can freely interact with the Web on our behalf.
Ruben Verborgh is a postdoctoral fellow of the Research Foundation Flanders and a researcher in semantic hypermedia at Ghent University – iMinds, Belgium. He explores the connection between Semantic Web technologies and the Web’s architectural properties, with the ultimate goal of building more intelligent clients.

Michel Dumontier is an Associate Professor of Medicine in the Stanford Center for Biomedical Informatics Research at Stanford University. His research focuses on computational methods to organize data and services for biomedical knowledge discovery.

References


