ActivityPub: From Decentralized to Distributed Social Networks

A White Paper from Rebooting the Web of Trust V

by Christopher Webber & Manu Sporny

INTRODUCTION

ActivityPub is a protocol being developed at the W3C for the purpose of building federated social systems. Users can use implementations of ActivityPub like Mastodon and MediaGoblin as libre alternatives to large siloed social networking systems such as Facebook, Twitter, YouTube, and Instagram[1].

In general ActivityPub follows the client-server paradigm that has been popular on the World Wide Web, while restoring some level of decentralization. Current implementations of ActivityPub go as far as to bring a level of decentralization akin to email[2], but there are many opportunities to go further.

By attaching public keys to the profiles of actors (users) on the network and using Linked Data Signatures, we can add a web of trust to the federated social web and use it to enhance user privacy and to assert the integrity of messages sent over the network.

By using a decentralized identifier system such as Decentralized Identifiers (DIDs) we can move fully from a decentralized to a distributed system[3], by escaping the core centralization mechanisms of DNS and SSL certificate authorities.

At this point, users could even optionally transition from a client-server model system to a fully peer-to-peer system.

ACTIVITYPUB OVERVIEW

This section is borrowed from the ActivityPub standard's Overview section; if you are already familiar with ActivityPub then you may skip this section.

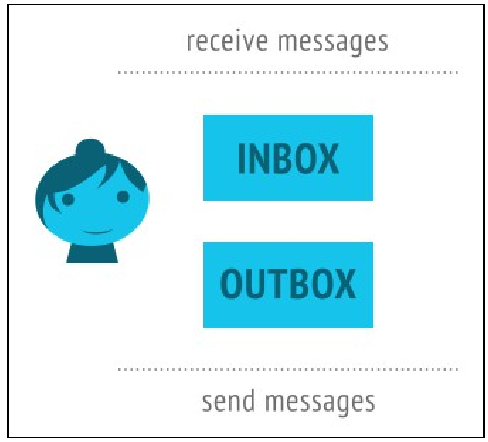
ActivityPub provides two layers:

- A server-to-server federation protocol: so decentralized websites can share information
- A client-to-server protocol: so users can communicate with ActivityPub using servers, from a phone or desktop or web application or whatever

ActivityPub implementations can implement just one of these things or both of them.

However, once you've implemented one, it isn't too many steps to implement the other, and there are a lot of benefits to both (making your website part of the decentralized social web and able to use clients and client libraries that work across a wide variety of social websites).

In ActivityPub, every actor (users are represented as "actors" here) has:



- An inbox: How they get messages from the world
- An outbox: How they send messages to others

These are endpoints, or really, just URLs which are listed in the ActivityPub actor's ActivityStreams description. (More on ActivityStreams later.)

Here's an example of the record of our friend Alyssa P. Hacker:

```
{
  "@context":
    "https://www.w3.org/ns/activitystreams",
  "type": "Person",
  "id": "https://social.example/alyssa/",
  "name": "Alyssa P. Hacker",
  "preferredUsername": "alyssa",
  "summary": "Lisp enthusiast hailing from MIT",
  "inbox": "https://social.example/alyssa/inbox/",
  "outbox": "https://social.example/alyssa/outbox/",
  "followers": "https://social.example/alyssa/followers/",
  "following": "https://social.example/alyssa/following/",
  "liked": "https://social.example/alyssa/liked/"
}
```

ActivityPub uses ActivityStreams for its vocabulary. This is pretty great because ActivityStreams includes all the common terms you need to represent all the activities and content flowing around a social network.

It's likely that ActivityStreams already includes all the vocabulary you need, but even if it doesn't, ActivityStreams can be extended via JSON-LD.

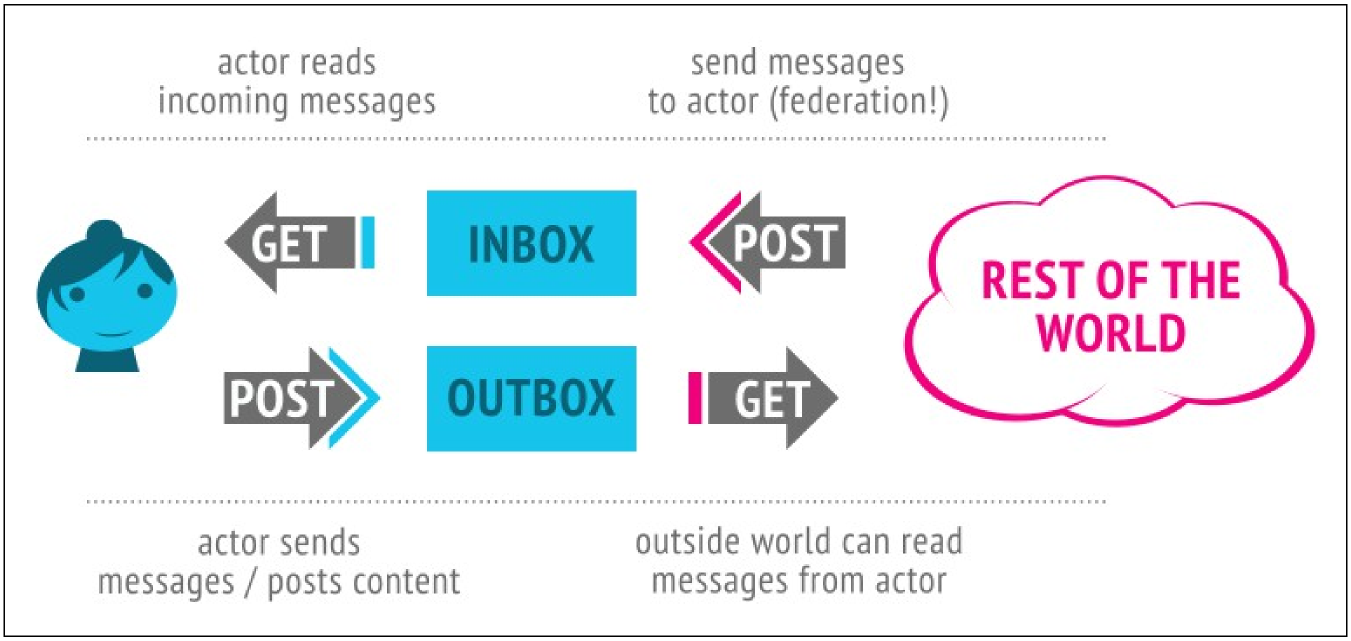
If you know what JSON-LD is, you can take advantage of the cool linked data approaches provided by JSON-LD. If you don't, don't worry, JSON-LD documents and ActivityStreams can be understood as plain old simple JSON. (If you're going to add extensions, that's the point at which JSON-LD really helps you out.)

So, okay. Alyssa wants to talk to her friends, and her friends want to talk to her! Luckily these "inbox" and "outbox" things can help us out. They both behave differently for GET and POST.

So the full workflow is:

- You can POST to someone's inbox to send them a message (server-to-server / federation only... this *is* federation!)
- You can GET from your inbox to read your latest messages (client-to-server; this is like reading your social network stream)

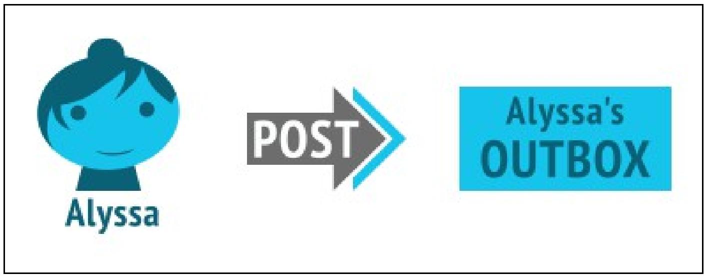
- You can POST to your outbox to send messages to the world (client-to-server)
- You can GET from someone's outbox to see what messages they've posted, or at least the ones you're authorized to see. (client-to-server and/or server-to-server)



Of course, if that last one (GET'ing from someone's outbox) was the only way to see what people have sent, this wouldn't be a very efficient federation protocol! Indeed, federation happens usually by servers posting messages sent by actors to actors on other servers' inboxes.

Let's see an example! Let's say Alyssa wants to catch up with her friend, Ben Bitdiddle. She lent him a book recently and she wants to make sure he returns it to her. Here's the message she composes, as an ActivityStreams object:

```
{
  "@context": "https://www.w3.org/ns/activitystreams",
  "type": "Note",
  "to": ["https://chatty.example/ben/"],
  "attributedTo": "https://social.example/alyssa/",
  "content": "Say, did you finish reading that book I lent you?"
}
```



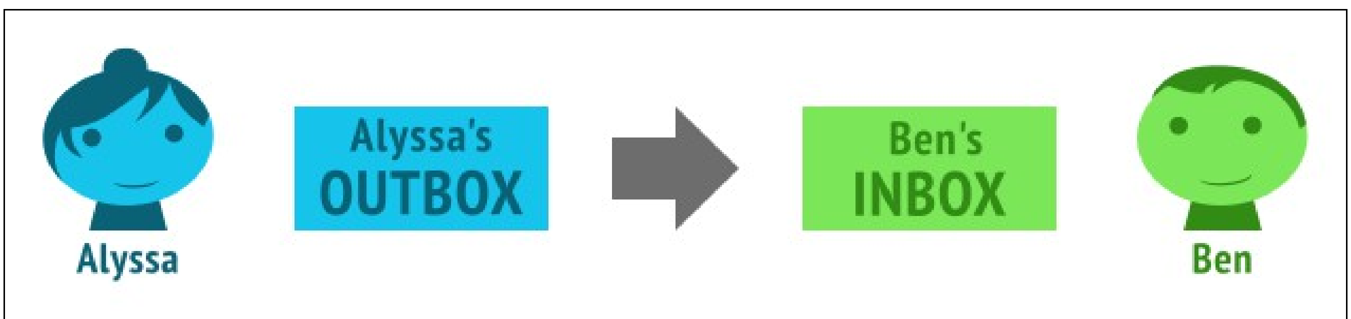
This is a note addressed to Ben. She POSTs it to her outbox.

Since this is a non-activity object, the server recognizes that this is an object being newly created, and does the courtesy of wrapping it in a Create activity. (Activities sent around in ActivityPub generally follow the pattern of some activity by some actor being taken on some object. In this case the activity is a Create of a Note object, posted by a Person.)

```
{
  "@context": "https://www.w3.org/ns/activitystreams",
  "type": "Create",
  "id": "https://social.example/alyssa/posts/a29a6843-9feb-4c74-...",
  "to": ["https://chatty.example/ben/"],
  "actor": "https://social.example/alyssa/",
  "object": {
    "type": "Note",
    "id": "https://social.example/alyssa/posts/49e2d03d-b53a-4c4c-...",
    "attributedTo": "https://social.example/alyssa/",
    "to": ["https://chatty.example/ben/"],
    "content": "Say, did you finish reading that book I lent you?"
  }
}
```

Alyssa's server looks up Ben's ActivityStreams actor object, finds his inbox endpoint, and POSTs her object to his inbox.

Technically these are two separate steps... one is client-to-server communication, and one is server-to-server communication (federation). But, since we're using them both in this example, we can abstractly think of this as being a streamlined submission from outbox to inbox.



A while later, Alyssa checks what new messages she's gotten. Her phone polls her inbox via GET, and amongst a bunch of cat videos posted by friends and photos of her nephew posted by her sister, she sees[4] the following:

```
{
  "@context": "https://www.w3.org/ns/activitystreams",
  "type": "Create",
  "id": "https://chatty.example/ben/p/51086",
```

```
  "to": ["https://social.example/alyssa/"],
  "actor": "https://chatty.example/ben/",
  "object": {
    "type": "Note",
    "id": "https://chatty.example/ben/p/51085",
    "attributedTo": "https://chatty.example/ben/",
    "to": ["https://social.example/alyssa/"],
    "inReplyTo": "https://social.example/alyssa/posts/49e2d03d-b53a-...",
    "content": "Argh, yeah, sorry, I'll get it back to you tomorrow.
                I was reviewing the section on register machines,
                since it's been a while since I wrote one."
  }
}
```

Alyssa is relieved, and likes Ben's post:

```
{
  "@context": "https://www.w3.org/ns/activitystreams",
  "type": "Like",
  "id": "https://social.example/alyssa/posts/5312e10e-5110-42e5-...",
  "to": ["https://chatty.example/ben/"],
  "actor": "https://social.example/alyssa/",
  "object": "https://chatty.example/ben/p/51086"
}
```

She POSTs this message to her outbox. (Since it's an activity, her server knows it doesn't need to wrap it in a Create object.) Feeling happy about things, she decides to post a public message to her followers. Soon the following message is blasted to all the members of her followers collection, and since it has the special Public group addressed, is generally readable by anyone.

```
{
  "@context": "https://www.w3.org/ns/activitystreams",
  "type": "Create",
  "id": "https://social.example/alyssa/posts/9282e9cc-14d0-42b3-...",
  "to": ["https://social.example/alyssa/followers/",
         "https://www.w3.org/ns/activitystreams#Public"],
  "actor": "https://social.example/alyssa/",
  "object": {
    "type": "Note",
    "id": "https://social.example/alyssa/posts/d18c55d4-8a63-4181-...",
    "attributedTo": "https://social.example/alyssa/",
    "to": ["https://social.example/alyssa/followers/",
           "https://www.w3.org/ns/activitystreams#Public"],
    "content": "Lending books to friends is nice.
                Getting them back is even nicer! :)"
  }
}
```

BRINGING PUBLIC KEY CRYPTOGRAPHY TO THE FEDERATED SOCIAL WEB

We can dramatically improve the state of the federated social web by having each actor on the system hold a public and private keypair, and by having actors have their public key attached directly to their actor object:

```
{
  "@context": ["https://www.w3.org/ns/activitystreams",
               "https://w3id.org/security/v1"],
  "id": "https://schemers.example/u/alyssa",
  "type": "Person",
  "name": "Alyssa P. Hacker",
  "publicKey": [{
    "id": "https://schemers.example/u/alyssa#main-key",
    "owner": "https://schemers.example/u/alyssa",
    "publicKeyPem": "-----BEGIN PUBLIC KEY-----\r\n..."
  }]
}
```

This provides significant improvements to the system, which we explore below.

Signing objects

Sharing messages is common in social networks. But how can you verify that someone really said what they claimed?

The user Mallet is trying to cause havoc in their social network. They pretend to "share"[5] the following post that they claim Alyssa sent to the pasta-enthusiasts group, which Ben is a member of.

```
{
  "@context": "https://www.w3.org/ns/activitystreams",
  "type": "Announce",
  "id": "https://havoc.example/~mallet/p/90815",
  "to": ["https://pastalovers.example/groups/pasta-enthusiasts/"],
  "actor": "https://havoc.example/~mallet/",
  "object": {
    "type": "Note",
    "id": "https://social.example/alyssa/posts/63cc87ec-416e-437d-...",
    "attributedTo": "https://social.example/alyssa/",
    "to": ["https://havoc.example~mallet/"],
    "content": "Tortellini is a poor and disgusting imitation of ravioli.
                Any chef serving tortellini should hang up their aprons
                in disgrace and never cook again.",
    "signature": {
      "type": "RsaSignature2017",
      "creator": "https://social.example/alyssa/",
      "created": "2017-09-23T20:21:34Z",
      "nonce": "e3689a56da9b4bc",
      "signatureValue": "mJfe5OCb7J3WwI...8t5/m="
    }
  },
  "signature": {
    "type": "RsaSignature2017",
    "creator": "https://social.example/alyssa/",
```

```
        "created": "2017-09-23T21:32:21Z",
        "nonce": "22e8e7683f56c08bb873",
        "signatureValue": "wTjLtnZVYF79pq9Ts...OU1jYPSjvcE2jNc="
      }
    }
```

Ben's server, or even the server hosting **pastalovers.example**, can check the signature against the **publicKey** listed on Alyssa's actor object. This check fails, and so Mallet's attempt at slander of Alyssa amongst the pasta enthusiast community fails. While the above example looks at protecting against a malicious interaction, forwarding and sharing content is desirable for positive reasons.

[6]One common problem in federated social networks that support private interactions is that a conversation can become fragmented: if Ben is posting to private collection she has curated containing both his friends and coworkers, and members of coworkers can't see who is in the private family collection, when they address to include the family in the conversation they can't traverse the collection of family actors to deliver to all relevant participants. (This "ghost replies" problem happens frequently on federated networks even when messages are being sent to the actor's own `followers`, where breaks tend to happen across server boundaries.)

ActivityPub includes a solution to this via a forwarding mechanism, but the solution does not really work without signatures, as the forwards are happening indirectly rather than from the "same origin/domain", so servers are unable to check/trust that the content is as claimed. Even if the receiving server tries to look up the object the receiving actor's credentials, access control may not have been enabled for the actor who was forwarded to, since the commenter had no way of knowing who was in the private collection to enable access for.

This is a frequently requested feature in federated social networks, so we should ensure that the necessary public key infrastructure is provided[7].

An easier to use web of trust?

The PGP-style "web of trust" has been around for some time now, but the term "web of trust" is somewhat mired by the historically most popular method by which the trust network has populated. Key signing parties, while effective, have never taken off beyond a very small set of the population. Such parties are rewarding but difficult for most of the population to attend and organize, and even more difficult still is learning the (generally) command line tooling necessary to participate in the system. While some work has been done in this area (for example with Monkeysign and Gibberbot), it would be even better if building your trust network was incidental to participating in the network[8].

To a certain extent, this could come "for free, with caveats" in ActivityPub deployments that exist today, where subscriptions and object lookup are done over HTTPS. Merely by sending a follow request (or some other action connecting users on the social graph) a certain amount of trust between users can be expressed. Keys can be looked up and recorded at actor profile urls, and users can even observe and share information about whom else they know on the social network.

There's a major caveat using HTTPS for these lookups requires trust in SSL certificate authorities. Better than nothing, but not great, and not the distributed systems we want. Furthermore, a malicious actor can still trick users; a user may believe they are subscribing to `https://social.example/alyssa/`, but perhaps Mallet tricked them into subscribing to `https://social.example/alyssaa/` instead[9].

Happily there are other ways to encourage stronger trust networks. Carl Ellison's paper *Establishing Identity Without Certification Authorities* describes several classes of relationships amongst users, and many Off The Record clients (such as available in Pidgin, etc) provide interfaces for verifying challenges between users. Users on a federated social network could be provided an opportunity to perform a textual challenge, perform a brief video call where they verify a shared code (as done in Jitsi), or scan a QR code (as in Monkeysign and Gibberbot) to establish stronger trust that an actor on the network is the entity they claim to be. The level of trust gained could be signed, recorded, and itself propagated as appropriate throughout the network. This kind of mechanism would work nicely even in a system like DIDs, where a human-readable identifier does not exist.

End-to-end encryption

A malicious server administrator may still snoop on all communication of participants on a system. Even a non-malicious administrator may be coerced into snooping on their users, or may have their entire system compromised without their knowledge. SSL Certificate Authorities may also be compromised into giving out fake certificates, allowing man in the middle attacks that neither the user nor server administrator may be aware of.

End-to-end encryption can solve this (with some tradeoffs); in this case, rather than having the server manage the public and private keys of a user, a user may provide a public key on their actor object to which only their own computer(s) hold the corresponding private key. Other actors on the network may then send an object encrypted to the actor's inbox. For example, an actor may receive the following object[10] in their inbox:

```
{
  "@context": ["https://securityns.example/",
               "https://www.w3.org/ns/activitystreams"],
  "type": "EncryptedEnvelope",
  "encryptedMessage": "-----BEGIN PGP MESSAGE-----\r\n...",
  "mediaType": "application/ld+json;
                profile=\"https://www.w3.org/ns/activitystreams\""
}
```

The server would put this object in the user's inbox, but if only the user's own computers hold the key, even the server would be unable to read the contents held within the envelope.

Upon retrieving the object from the server via the client-to-server protocol, the user's client can decrypt the message. In this case, the message went directly to Alyssa's inbox. Upon decrypting the component in encryptedMessage, another object is found:

```
{
  "@context": "https://www.w3.org/ns/activitystreams",
  "type": "Note",
  "id": "https://chatty.example/ben/p/86187",
  "to": ["https://social.example/alyssa/"],
  "attributedTo": "https://chatty.example/ben/",
  "content": "Up for some root beer floats at my friend's house?
              Here's the address: …"
}
```

Note that while this improves privacy, it does come with several tradeoffs:

- ActivityPub contains an entire suite of server side side-effects for federating common activities on a social network. For example, a Like object will increment a counter of how often a post has been liked, and even add that liked object to both the user's collection of liked objects as well as a collection of all users who have liked this object. Since servers are unable to observe data being sent across the network, these kinds of side effects will break. The server will also be unable to provide additional features such as being able to have server-based indexing of messages for easy search[11].

  In a "more peer-to-peer" system (as discussed in the Distributed identity section) this becomes less of an issue because the distinction between client server blurs. Nevertheless, for existing client-to-server implementations, this is a strong issue to consider.

- User maintenance of keys in end-to-end encryption systems is known to be a difficult user experience problem.

- Key recovery is even harder. DIDs explore a method for key recovery, but this will not help users read old messages encrypted with keys they no longer have and which the original senders cannot send (or do not know how to).

DISTRIBUTED IDENTITY

ActivityPub implementations at the present moment rely on HTTPS as their transport, which in turn relies on two centralized systems: DNS and SSL certificate authorities. Is there any way to bring self-sovereignty to the federated social web?

Thankfully there is; ActivityPub was written intentionally to be layerable on any protocol that can support HTTP GET and POST verbs. The Decentralized Identifiers specification looks to be a good fit for ActivityPub.

The simplest version of this can be seen simply by replacing the actor ids with DIDs. To transform an example from the overview from:

```
{
  "type": "Note",
  "attributedTo": "https://social.example/alyssa/",
  "to": ["https://chatty.example/ben/"],
  "content": "Say, did you finish reading that book I lent you?"
}
```

to:

```
{
  "type": "Note",
  "attributedTo": "did:example:d20Hg0teN72oFeo0iNYrblwqt",
  "to": ["did:example:nJx2fgreaSfCujA0kMsiEW8Oz"],
  "content": "Say, did you finish reading that book I lent you?"
}
```

Gosh! That was simple-ish. All we did was replace the human-readable identifiers representing the users with DIDs. If we look up Alyssa's DID based id, we can retrieve her actor object as a DDO, but this time there is extra information:

```
{
  "@context": ["https://example.org/did/v1",
               "https://www.w3.org/ns/activitystreams"],
  "id": "did:example:d20Hg0teN72oFeo0iNYrblwqt",
  "activityPubService": {
    "id": "did:example:d20Hg0teN72oFeo0iNYrblwqt#services/ActivityPub",
    // ActivityPub actor information
    "type": "Person",
    "name": "Alyssa P. Hacker",
    "preferredUsername": "alyssa",
    "summary": "Lisp enthusiast hailing from MIT",
    "inbox": "https://9GaksjPhy0mWToTV.onion/alyssa/inbox/",
    "outbox": "https://9GaksjPhy0mWToTV.onion/alyssa/outbox/",
    "followers": "https://9GaksjPhy0mWToTV.onion/alyssa/followers/",
    "following": "https://9GaksjPhy0mWToTV.onion/alyssa/following/",
    "liked": "https://9GaksjPhy0mWToTV.onion/alyssa/liked/"
  },
  // DDO information
  "owner": [{
    "id": "did:example:d20Hg0teN72oFeo0iNYrblwqt#key-1",
    "type": ["CryptographicKey", "EdDsaPublicKey"],
    "curve": "ed25519",
    "expires": "2017-02-08T16:02:20Z",
    "publicKeyBase64": "lji9qTtkCydxtez/bt1zdLxVMMbz4SzWvlqgOBmURoM="
  }, {
    "id": "did:example:d20Hg0teN72oFeo0iNYrblwqt#key-2",
    "type": ["CryptographicKey", "RsaPublicKey"],
    "expires": "2017-03-22T00:00:00Z",
    "publicKeyPem": "----BEGIN PUBLIC KEY-----\r\n.."
  }],
  "control": [{
    "type": "OrControl",
    "signer": [
        "did:example:d20Hg0teN72oFeo0iNYrblwqt",
        "did:example:8uQhQMGzWxR8vw5P3UWH1j"
    ]
  }],
  "created": "2002-10-10T17:00:00Z",
  "updated": "2016-10-17T02:41:00Z",
  "signature": {
    "type": "RsaSignature2016",
    "created": "2016-02-08T16:02:20Z",
    "creator": "did:example:8uQhQMGzWxR8vw5P3UWH1j#key/1",
    "signatureValue": "IOmA4R7TfhkYTYW8...CBMq2/gi25s="
  }
}
```

Hoo! That's a lot of additions. Except here we see an example of Alyssa's profile that is entirely free of traditional centralized DNS authorities. We were able to look up Alyssa's object via her DID, but we still have access to all her endpoints, which in this case are pointing to Tor Hidden Services. No central DNS required!

Maybe in the future there will even be a protocol – let's call it `httpeer` – which supports all the standard HTTP verbage, but over some other peer-to-peer network. The DID spec supports service endpoints, and Alyssa could take advantage of these to use her DID as base of the `inbox`, `outbox`, etc URIs. Here's a cut down and modified version of the previous example:

```
{
  "@context": ["https://example.org/did/v1",
               "https://www.w3.org/ns/activitystreams"],
  "id": "did:example:d20Hg0teN72oFeo0iNYrblwqt",
  "activityPubService": {
    "id": "did:example:d20Hg0teN72oFeo0iNYrblwqt#services/ActivityPub",
    // ActivityPub actor information
    "type": "Person",
    "name": "Alyssa P. Hacker",
    "preferredUsername": "alyssa",
    "summary": "Lisp enthusiast hailing from MIT",
    "inbox": "did:example:d20Hg0teN72oFeo0iNYrblwqt/inbox/",
    "outbox": "did:example:d20Hg0teN72oFeo0iNYrblwqt/outbox/",
    "followers": "did:example:d20Hg0teN72oFeo0iNYrblwqt/followers/",
    "following": "did:example:d20Hg0teN72oFeo0iNYrblwqt/following/",
    "liked": "did:example:d20Hg0teN72oFeo0iNYrblwqt/liked/"},
  // DDO information goes here
  "httpeerService": {
    "nodeId": "dI0tuXjISZEadSH6QV9EhBEdccL4ouePdF8P57BJ"
  }
}
```

Now that's an identity system!

APPEND ONLY SYSTEMS AND CONTENT ADDRESSED STORAGE

Finally, it's worth mentioning the idea of moving ActivityPub to an entirely append-only, content-addressed system for object storage, "modification", and retrieval. Much success has been seen in recent years with these systems; enacting this change would allow for many of the side effects in the federation system to be dropped entirely. We leave this as a topic for a future paper.

CONCLUSIONS

ActivityPub goes a long way towards providing a standardized way to move the social web from isolated, centralized silos towards the decentralized nature that the World Wide Web is meant to encompass. Still, there is much to be done and improved. Yet there are risks in trying to engineer the right system all at once, and great is well known to be the enemy of good.

Thankfully we do not need to throw out what we have to make the improvements that are discussed in this paper. ActivityPub already exists and works, and we can incrementally improve the systems we have and blur the line between the federated social web that works and more peer-to-peer systems which are desirable. By adding public key infrastructure and distributed identifiers to ActivityPub we can move from a decentralized system to a distributed one and truly build a network that is both self-sovereign and social.

ACKNOWLEDGMENTS

Thanks to Evan Prodromou and Owen Shepherd for working on initial revisions of the ActivityPub standard. Thanks also to Jessica Tallon for being co-editor on ActivityPub and everyone who helped make ActivityPub happen, which is no small list. (Some of those people caught typos in the original version of the overview, as included in ActivityPub.)

Thanks to Manu Sporny and Stephen Webber for thoughts and feedback about how to make ActivityPub into a more robust distributed system. Thanks to Dave Longley for pointing to the vocabulary drift / ambiguity of the terms "decentralized" and "distributed", which lead to the addition of Paul Baran's diagrams and some terminology clarification. Thanks to Morgan Lemmer-Webber for the patience and for careful proofreading of this document.

Thanks to Spec-Ops and Digital Bazaar for supporting my work/time on Verifiable Claims/Credentials. Though separate from my work on ActivityPub, obviously I've been thinking a lot about how to combine them this whole time.

Thanks also to mray for the gorgeous illustrations in the overview section.

ADDITIONAL CREDITS

Authors: Christopher Webber & Manu Sporny

About Rebooting the Web of Trust

This paper was produced as part of the Rebooting the Web of Trust V design workshop. On October 3rd through October 5th, 2017, over 50 tech visionaries came together in Cambridge, Massachusetts to talk about the future of decentralized trust on the internet with the goal of writing 3-5 white papers and specs. This is one of them.

Preliminary Workshop Sponsors List: BigChainDB, Blockchain Lab, Digital Contract Design, IDEO, IPFS, Protocol Labs, Toni Lane Casserly

Workshop Producer: Christopher Allen

Workshop Facilitators: Christopher Allen, with additional paper editorial & layout by Shannon Appelcline.

What’s Next?

The design workshop and this paper are just starting points for Rebooting the Web of Trust. If you have any comments, thoughts, or expansions on this paper, please post them to our GitHub issues page:

https://github.com/WebOfTrustInfo/rebooting-the-web-of-trust-fall2017/issues

The next Rebooting the Web of Trust design workshop is scheduled for early 2018 on the west coast of the USA. If you'd like to be involved or would like to help sponsor these events, email:

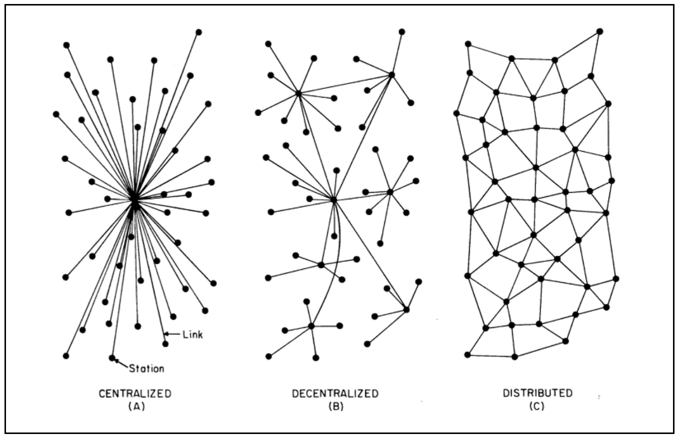
ChristopherA@LifeWithAlacrity.com

---

1 Of course, there is nothing stopping current-silos of social networking from adopting ActivityPub, would they be willing to un-silo their users.

2 Observant readers may note that email is no longer as decentralized of a system as it once was. Consider this a lesson that a protocol alone cannot build a distributed network; the community must build and maintain a healthy number of nodes and avoid the temptation to let a few large providers control the space of a federated network.

3 It is worth spending some time to discuss what is meant by "centralized" versus "distributed" versus "decentralized". In the figure above we see images from Paul Baran's 1964 paper on the subject, and from these shapes we can see the kinds of shapes we mean: social silos resemble the the spoke-like centralized model, client-server federated social networks resemble the tree-like decentralized model, and a peer-to-peer network resembles the mesh-like distributed model. Since the writing of that paper there has been significant vocabulary drift (perhaps because English is such a decentralized/distributed language) and clarifying the meaning of these terms can be difficult. (In one popular post on the Ethereum Stack Exchange, a diagram that looks almost exactly like Baran's diagram appears, but with the Decentralized and Distributed labels reversed!) The goal of this paper is really to seek out the systems that promote the greatest amount of reliability, security, and user autonomy, and some of the methods discussed, such as public key cryptography, promote both. Nonetheless, when the terms "decentralized" and "distributed" are used and meaning is to be sought out, look to Baran, for sometimes pictures are more descriptive than words.



4 Alyssa probably would likely not see the JSON-LD objects directly as described here, but the author believes that some narrative context still assists in the explaination of a UI-agnostic protocol.

5 `Announce` is essentially `Share` in ActivityStreams. The author of this document is not responsible for that terminology decision.

6 In ActivityPub, `Collection` objects may be used to contain sets of objects. Users of the system can curate sets of actors in collections that are publicly or privately readable which may be used for the addressing of distributed objects (similar to Google+'s circles or Diaspora's aspects). Indeed, even the actor's `followers` is a `Collection` like this!

7 Several decisions need to be made when storing signatures on objects which themselves reference other signed objects that may mutate, and this is currently a topic of open discussion. This may motivate more work on append only systems and content addressed storage. Existing implementations which operate in a mutation-prone environment must decide between letting signatures referencing mutated objects fail, including such objects recursively on every parent object, or employ some sort of content addressing of objects stored by the revision seen. The latter two options may pose some challenge to highly relational systems which were not originally designed with signatures in mind.

8 GNU Ring is an interesting example of a peer-to-peer social network system where a user's identity is actually their fingerprint. While not the first system to have this concept, it's very pleasant to see in action (and the interface is itself aesthetically pleasing); to build up your buddy list is quite literally to build your web of trust.

9 There are an incredible number of unicode hacks, which can trick even the most careful of technical users as well.

10 `https://securityns.example/` is an imaginary json-ld context which is used only as a placeholder for the terms of `EncryptedEnvelope` and `encryptedMessage`. Perhaps in the future terms along these lines (maybe with better names) would appear in one of the other contexts/namespaces that appear in this document.

11 This is not unlike how PGP-wrapped email works. Receiving PGP-encrypted email means that a webmail interface would be unable to search through your messages. However, that does not mean searching is impossible; some programs like mu / mu4e can index encrypted email locally and provide such a search interface, on a user's local machine.