Rigging Specifications

T.R.I.E.
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1 Introduction

This document serves as a normative specification of *rigging*. A well-formed rig links two things together, such that the integrity of the one is extended to the other. By continuing to build the rig, this integrity-at-a-distance can be maintained between them even if the first is entirely oblivious about the existence of the second.

Rigging is employed a variety of places, including within TODA files, where the proof of provenance is composed of rigs. For a formal analysis of the properties of rigging, see [1]

This document builds up rigging gradually, starting from the smallest components, but we begin with a brief top down overview of the architecture.

A *rig* is a cryptographic data structure that binds an untrusted *leadline* to a trusted *corkline*. The rig provides a simple but powerful guarantee: if the corkline has not equivocated, then the leadline has not equivocated. This holds true regardless of what any other line in the rig has done[1].

Rigs are made by composing *hitches*. A hitch is itself a minimal rig: it provides the rig guarantee over its *topline* and its *footline*. Hitches compose horizontally by *splicing* together and vertically by *lashing* together with existing rigs, allowing them to maintain rig structures under arbitrarily complex circumstances. Checking the validity of a rig is primarily a matter of checking the validity of its hitches and their composition operations.

A *line* is an object that evolves over time. Each update to a line is called a *twist*. Lines are defined by (hash-based) identifiers in their constituent twists, so they have unique histories but potentially equivocal futures.

[*]TODAQ

[1]Note that the rigs described in this work belong to $G_{\uparrow}$, a supportive guild, as described in [1]

Each twist is composed of *atoms*, the smallest unit of meaning in a rig. In addition to their structural purpose in a rig twists can carry semantic content, which is also expressed as atoms – the subject of the next section.

2 Atoms

The data in a rig is composed of individual atoms. Each atom pairs an identifier (generally a hash) and its corresponding packet. A packet wraps content, adding descriptions of its length and structural shape. This serialization scheme is the Atomic Serialization Protocol.

2.1 Identifiers

An *identifier* is a data structure with the following layout:

1 byte	(hashing) algorithm
n bytes	the output of the algorithm

The current hashing algorithm identifiers:

ID byte	Name	Length	Description
`0x00`	NULL	0 bytes	Has specialized meaning in rigs
`0x22`	Symbol	32 bytes	Arbitrary bytes
`0x41`	SHA-256	32 bytes	The 256 bit SHA-2 digest in FIPS PUB 180-4
`0x42`	Blake3-256	32 bytes	(not yet implemented)
`0x43`	Blake3-512	64 bytes	(not yet implemented)
`0xFF`	UNIT	0 bytes	

The NULL, SYMBOL, and UNIT algorithms all operate without an input packet.

In the NULL and UNIT case, this lack of entropy in the input space is characterized by a zero-length output. Thus NULL and UNIT atoms have one byte in total length (the algorithm byte). By definition nothing hashes to NULL or UNIT (they have no matching preimage)[2].

The Symbol algorithm `0x22` is always followed by 32 arbitrary bytes. They provide the capacity for meaningless names to be created. Symbols, like the NULL and UNIT hashes, are complete atoms unto themselves[3]. An identifier whose algorithm is SYMBOL, is called a symbol. Like NULL and UNIT, symbols have no matching preimage, by definition.

Each SHA-256 identifier is characterized by a 32 byte output, hence each identifier using the SHA-256 hash algorithm is 33 bytes in total, with the first byte always being 0x41.

Additional identifier algorithms are expected to be added over time, and implementations must be designed to support the addition of new algorithms.

[2]Typically the NULL hash is used to signify nothing, either at the start of a sequence or over some duration, and the UNIT hash is used to terminate a sequence.

[3]Symbols are used whenever a name must be introduced: occasionally within the rigging structure, but much more frequently within the cargo.

Note that algorithm outputs may have lengths other than the 32 bytes of SHA-256.

Notationally, given an identifier `I`, we employ the following selectors:
`alg(h)` is the algorithm identifier byte of `I`,
`hash(I)` is the hash function identified by `alg(I)`, and
`digest(I)` is the output of `hash(I)` applied to the data being hashed, so

$$\texttt{I} = \texttt{alg}(\texttt{I})|\texttt{digest}(\texttt{I})$$

For NULL and UNIT `digest(I)` and `hash(I)` are undefined. For symbols, `digest(I)` is the symbol's 32 bytes, and `hash(I)` is the constant function returning those 32 bytes, by definition.

2.2 Packets

A packet is structured content with the following layout:

1 byte	the shape
4 bytes	the content length (big endian)
n bytes	the content

The length slot counts the number of bytes of content, and can therefore accommodate content of up to four gigabytes, after which the data will need to be split across additional packets. This is a 32 bit integer in big endian byte order[4].

The packet itself is five bytes longer than the length count, because it does not include the shape and length bytes. Zero length packets are not currently allowed.

Notationally, given a packet `P`, we employ the following selectors:
`shape(P)` is the shape byte of `P`,
`length(P)` is the content length, and
`content(P)` is its content, so

$$\texttt{P} = \texttt{shape}(\texttt{P})|\texttt{length}(\texttt{P})|\texttt{content}(\texttt{P})$$

2.3 Atoms

Atoms are the topmost structure of the Atomic Serialization Protocol, and the fundamental representation of data structures in rigging. An atom is an identifier concatenated with its matching packet.

Given an identifier, its "matching packet" is one where applying the identifier's hash function to the packet yields the identifier's digest value. The whole packet must be hashed, including its shape and length values. Given an identifier `I` and a packet `P`, they match if and only if

$$\texttt{digest}(\texttt{I}) = \texttt{hash}(\texttt{I})(\texttt{P})$$

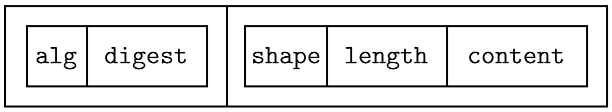
[4]In general, multibyte values used in the atomic serialization format are laid out in big endian byte order, though of course user supplied content may vary.

Notationally, given an atom `a`, we employ the following selectors:
`P(a)` is the packet contained in `a`,
`I(a)` is the identifier of that packet, and
`C(a)` is the content of that packet, so

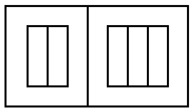
$$\mathtt{a} = \mathtt{I(a)}|\mathtt{P(a)}$$

$$\mathtt{C(a)} = \mathtt{content}(\mathtt{P(a)})$$

Diagramatically, we can represent an atom as follows:



Or condensed (we can also partially condense it):



2.4 List of Atoms

Identifiers are self-describing in terms of their length, as are packets. Atoms are therefore also self-describing in terms of their length, and can safely be concatenated one after the other, both at rest and in transit. A list of atoms is also referred to as a *lat*.

Symbols, NULL, and UNIT are complete atoms unto themselves, and are only used in-place within values. They are never included as top level atoms within a lat.

2.5 Errors

None of the error types at this level are fatal (so they should all be treated as having a status colour of "yellow"), but they do differ in their severity. Refer to Section 8.1 for more error handling commentary.

2.5.1 Atomic Errors

There are two cases that result in atomic errors:

- An atom's packet does not match its identifier
- A packet ends before its specified length

These atomic errors may result from a faulty transmission channel, and do not prove anything about the rig. They should generally be considered a case of missing information, not necessarily an error to be reported. The invalid data can be safely discarded, which may trigger a search for the actual atom with that identifier.

2.5.2 Nospec Errors

The following are nospec errors:

- An unknown algorithm byte in the identifier
- A packet with an unrecognized shape byte

Nospec errors occur when the client does not know how to interpret the atom. A nospec error may indicate that a new shape or algorithm is being used that this client has not been updated with, or they may arise from malformed atoms.

2.5.3 Lat Errors

A list of atoms that includes NULL, UNIT, or symbols, is a lat error. A lat error should normally be considered a sign of faulty transmission (though it can also be a sign of the list having been compiled by a non-compliant tool), and is non-fatal (i.e. has a status colour of "yellow").

While a list of atoms containing an atom with an atomic error, is reasonably likely to indicate a problem that warrants discarding much (or even all) of the atoms in the list; we abstain from identifying these cases as lat errors, in order to avoid assigning too many statuses to a single blob of data.

Lat errors are generally fixable by excising the errant atoms. Alternatively, the entire lat could be thrown away and retrieved again.

3 Shapes

The shape of an atom characterizes its structure. This provides constraints for the values that can occupy a given slot, and allows efficient parsing of structured content.

The currently defined shapes:

ID byte	Name	Class	Basic Structure
`0x48`	basic twist	twist	2 concatenated identifiers
`0x49`	basic body	body	6 concatenated identifiers
`0x63`	pairtrie	trie	A map of identifiers, expressed as a list of key-value pairs
`0x61`	hashes	list	A list of identifiers concatenated together
`0x60`	arb	arb	Arbitrary binary content

Values are constrained by shape class. For instance, a particular slot might require a twist. Any atom with a shape in the twist class will suffice. The basic twist shape is the first shape in the twist class[5].

The trie shape class specifically refers to Merkle tries, and all trie shapes carry the guarantee that a specific key has a unique value[6][7].

The pairtrie shape is the first shape in the trie shape class. It can be thought of as a Merkle trie with a particularly large branching factor. It is expressed as an ordered list of `key | value` pairs of identifiers[8], ordered by key[9].

The pairtrie content must consist of a strictly positive even number of identifiers, ordered as just described, with no duplicate keys. Any failure to meet these requirements is a shape error (as described in Section 3.1). In particular, it is a shape error for a pairtrie if:

- the pairtrie's keys are not listed in ascending order,
- the pairtrie's content contains duplicate keys,
- the pairtrie's content contains no identifiers (use NULL instead),
- the pairtrie's content contains an odd number of identifiers.

Additional trie shapes are expected to be added over time, and implementations must be designed to support the addition of new trie shapes.

Shapes are used by rigging constructs like twists to specify which atoms can occupy particular slots. Those specifications also include NULL as a shape class, which is occupied by exclusively by NULL.

Through their specification role, shapes provide the glue between the atom layer and higher layers of rigging.

3.1 Shape Errors

Shape errors occur when a packet provably fails to meet the requirements of its shape, such as a pairtrie that contains only a single identifier.

Shape errors are generally breaking. They represent a provably invalid construction, unlike an atomic or nospec error, which could change if additional information is provided. Only well-formed atoms can have shape errors, and in a well-formed atom the packet uniquely matches the identifier, and is therefore provably erroneous in the cases listed below.

Provably invalid constructions (aka "red errors") can be useful at higher levels of the system, because given a particular rig its red errors won't change,

[5] Most shape classes will gradually acquire more instances. In particular, additional body and trie shapes are already on the drawing board.

[6] Or no value at all, when that key can be proven to not exist in that Merkle trie. Except where stated otherwise, no value and the NULL value are treated as equivalent.

[7] In order to guarantee that a key has a unique value, it is required that it only appear once in the list; repetition of an entire key-value pair is still a shape error, even though only one value is provided for the key.

[8] e.g. `k0 | v0 | k1 | v1`

[9] Increasing Lusin–Sierpiński-Kleene–Brouwer ordering, to be specific.

whereas errors related to missing data (aka “yellow errors”) may disappear as more information arrives. This may provide opportunities for considering red errors to be a non-operation in cases where it is important to show something could not have happened, providing some amount of resilience to breaking failures of this kind[10].

The following are shape errors for a given packet:

- A packet of zero length
- Packet contains less than five bytes
- Packet's shape requires exactly N identifiers but its content does not contain exactly N identifiers
- Packet's shape requires concatenated identifiers, but the final identifier in its content does not have its required number of bytes (e.g. a SHA256 algorithm byte followed by 10 digest bytes).
- Packet's shape requires a shape-specific property that can be determined entirely within its atom and the atom does not have that property

4 Twists

Twists are the structure out of which all rigging is created.

The machinery of a twist is primarily concerned with establishing the connections to other twists that are needed to construct a well-formed rig (Section 7).

Both the basic twist shape and the basic body shape specify a fixed list of slots that must be filled by atoms with particular shapes. Inappropriately filled slots result in errors during rig checking.

4.1 Basic Twist Shape

Currently, the only representation of a twist is the basic twist (shape `0x48`). The basic twist shape (Section 3) has two slots, which contain identifiers for the following structures:

`body`	the identifier of the twist's *body*	basic body (shape `0x49`)
`sats`	the identifier of its *satisfactions trie*	trie shape or NULL

Thus a basic twist `t` has the form

$$\texttt{C(t)} \leftrightarrow \texttt{I(t.body)}|\texttt{I(t.sats)}$$

A twist `t` also has as its identifier `I(t)`.

To ensure uniqueness of the identifier, the identifier of the body must have the algorithm as the twist's own identifier. i.e. `alg(I(t))` must equal `alg(I(t.body))`.

[10]The current specification does not take advantage of this opportunity, as it is being considered in the larger context of proof structure resilience.

If the algorithm in the twist's identifier and the algorithm for its body identifier differ then the twist atom was not computed using `alg(I(t.body))`, and this is an error. In particular, since it is a failure to meet a structural requirement of the shape, and can be diagnosed without reference to data outside the atom with that shape, it is a shape error.

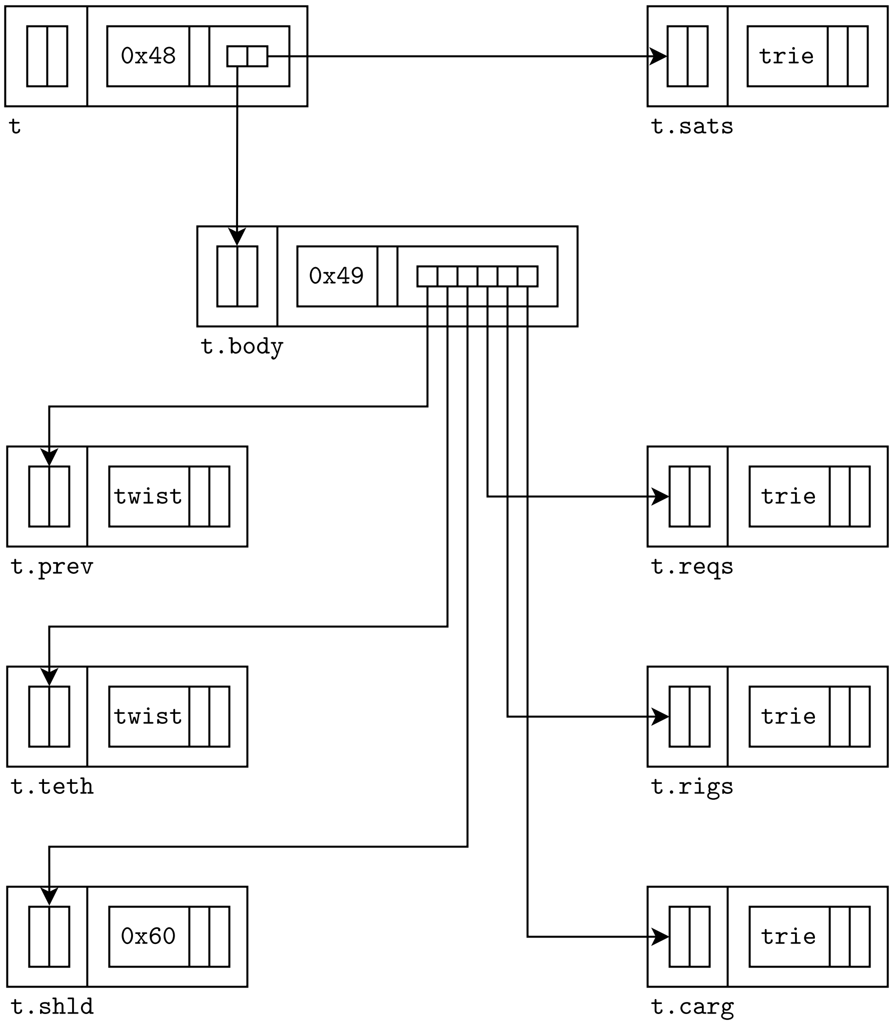
4.2 Basic Body Shape

A twist body must incorporate the following fundamental components into its structure:

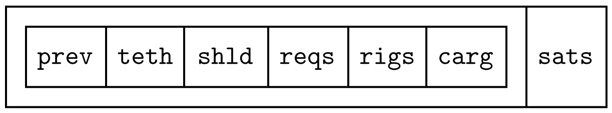
Component	Description	Required Shape
`prev`	previous twist	twist or NULL
`teth`	tether	twist, NULL, or UNIT
`shld`	temporary secret	arb or NULL
`reqs`	requirements trie	trie or NULL
`rigs`	rigging trie	trie or NULL
`carg`	cargo trie	trie or NULL

In the basic twist (shape `0x48`), the satisfactions often need to securely reference the rest of the twist data. Aggregating the identifiers of the first six components into a basic body (shape `0x49`), provides a body identifier that can be used as this secure reference:

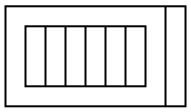
$$\texttt{C}(\texttt{t.body}) \leftrightarrow \texttt{I}(\texttt{t.prev})|\texttt{I}(\texttt{t.teth})|\texttt{I}(\texttt{t.shld})|\texttt{I}(\texttt{t.reqs})|\texttt{I}(\texttt{t.rigs})|\texttt{I}(\texttt{t.carg})$$



As structures are constructed in which twists are components, the above diagram is too much to reproduce in diagrams of those structures, so twists can be represented in a simplified form (like atoms were above):



Which can be further condensed (or partially condensed):



It is worth noting that since a basic twist body must consist of exactly 6 identifiers, and a basic twist must consist of exactly 2 identifiers; either of these shapes consisting of a different number of identifiers constitutes a shape error.

A twist with a non-NULL tether is called a *fast twist*, and it is made fast by hitching it as described in Section 6. A twist with NULL as the value of its tether slot is a *loose twist*.

The status objects that describe twist errors are found in section 9.2.

5 Lines

Each twist `t` has a unique previous twist, called its *predecessor*. Continuing this `prev` sequence reveals all the *ancestors* of `t`. We call such a linked list of ancestors a *line*. Each twist has a single line of ancestors.

In the forward direction a *successor* of a twist `t` has `t` as its `prev`, and so on. A sequence of such successive successors are *descendants* of `t`.

The line of succession of `t` is not inherently unique, as any new twist may set `t` as its `prev`. So our first concern is in determining the legitimacy of a claimed successor: does it satisfy the requirements of its predecessor? A twist that does is declared a *legitimate successor*.

In contrast to the notion of a line, which may extend indefinitely into the past and the future, a *segment* has precisely defined endpoints. A segment is a sequence of twists, each a legitimate successor of the last, and it is uniquely defined by its oldest (leftmost) and newest (rightmost) twists. We often use the word line when referring to segments, using the latter term only when disambiguation is necessary.

The status objects that describe line and segment errors are found in section 9.4.

5.1 Requirements and Satisfactions

Each twist may declare *requirements*. If it does, then its legitimate successors must carry *satisfactions* for those requirements. We refer to this system of requirements and satisfactions collectively as *reqsats*.

A twist's requirements are specified in its requirements trie `reqs`, and its satisfactions are provided in its satisfactions trie `sats`. Each entry in `reqs` must be satisfied by a corresponding entry in `sats`. When the `reqs` trie is NULL (and therefore has no keys), it is satisfied by a NULL `sats` trie.

More precisely:

```
function satisfies(x, y)
    if x.reqs == NULL
        if y.sats == NULL
            return true
        return false
    if y.sats == NULL
        return false
    if y.sats.keys != x.reqs.keys
        return false
    foreach (key in y.sats.keys)
        if satisfies(x.reqs[key], y.sats[key]) == false
            return false
    return true
```

With satisfaction defined, we can now also define validity of a twist as satisfying its `prev`'s requirements:

```
function valid(t)
    if t.prev == NULL
        return (t.sats == NULL)
    return satisfies(t.prev.reqs, t.sats)
```

The status objects that describe general requirement and satisfaction errors are found in section 9.3, with errors for more specific reqsat types described in their own sections.

5.1.1 Signature Reqsats

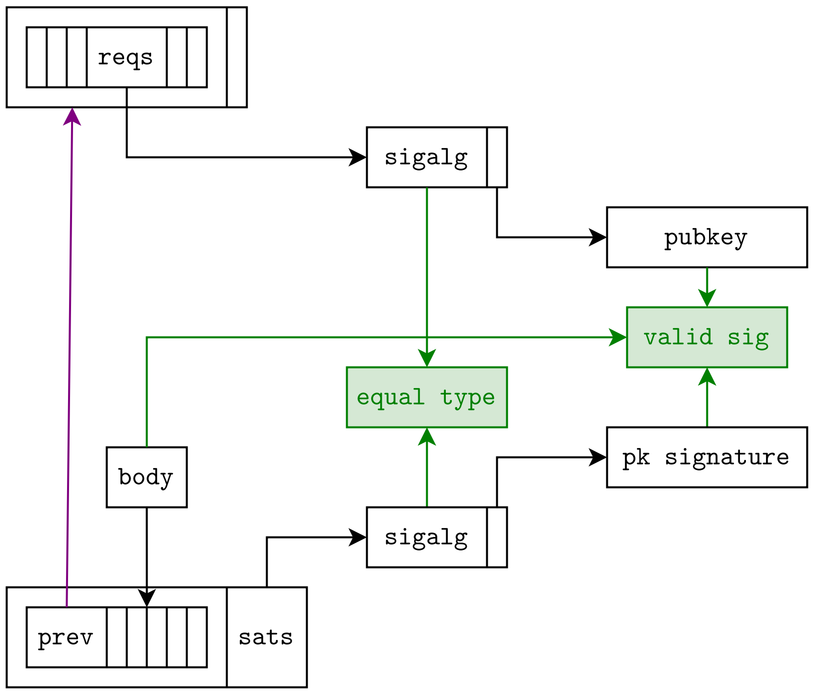
The simplest type of requirement is for a cryptographic signature over the successor using a public key cryptosystem. This provides holders of the private key exclusive control over the creation of legitimate successors.

For a signature reqsat, the key in the reqs trie designates a specific type of signature: for example, ECDSA using the secp256r1 curve and paramaters, as implemented in Java.

Let `sigalg` be a identifier representing a type of public key signature, `key.pub` and `key.priv` be represention of the public and private parts of a keypair for that signature type, and `sig(data, key)` be the signature of `data` by (the private part of) `key`; then we incorporate a signature reqsat as follows:

- `x.reqs[sigalg] = I(key.pub)`
- `y.sats[sigalg] = I(sig(body, key))`

The requirement is satisfied if and only if the signature is valid.



The signature algorithms currently available within requirements and satisfactions are:

secp256r1

identifier:	`0x22eabd2839f9e57cf2c372e686e5856cf651d7f07d0d396b3699d1d228b5931945`
public key format:	Java EC X509EncodedKeySpec (i.e. X.509)
signature format:	Java SHA256withECDSA (i.e. ANSI X9.62 signature of SHA256 hash) of body identifier (which might not use SHA256)

ed25519

identifier:	`0x223d5f4f95cdb1cdfc71014efa1a669fd42599a0ce2000d914a409e48bccaed584`
public key format:	Java Ed25519 key (i.e. X.509)
signature format:	Java Ed25519 (i.e. Ed25519 signature per RFC 8032)

5.1.2 List Reqsats

The next type of reqsat is a weighted list of reqsats, referred to as a *rslist*. This allows multiple keys to share control over the succession of an object.

In a requirements trie, the value associated with the rslist key (`0x22c9bf129a42fd9478fc42c986ba5b878667` must be the identifier of a list of reqlist entries `I(listEntries[0,...,n])`. Additionally, each entry is the identifier of a 2-entry list containing a weight and a requirement: `listEntries[i] = I(weight, reqs)` where each `weight` is an arb representing an unsigned 8-bit integer and each `reqs` is a requirements trie identifier (which is treated the same as a twist's requirements trie identifier).

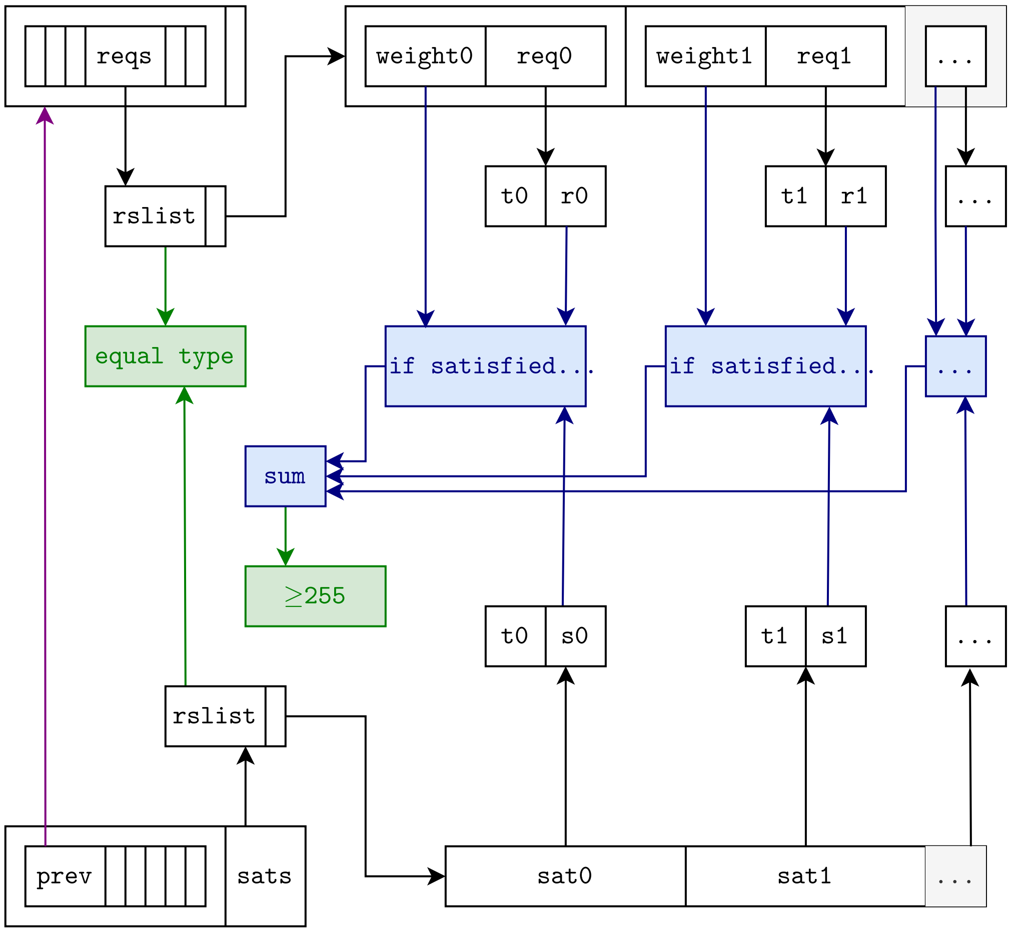
In a satisfactions trie, the value associated with the rslist key must be the identifier of a list of identifiers of satisfactions tries (the satlist) `I(listSats[0,...,n])`, where each `listSats[i]` is a satisfactions trie (with the same structure as a twist's satisfactions trie).

To satisfy the rslist requirement the length of `listEntries` must equal the length of `listSats`, and the sum of `listEntries[i].weight` across those values of `i` for which `listEntries[i].reqs` is satisfied by `listSats[i]` must be at least 255.

It should be noted that because the rslist uses the same format as twists for requirements tries and satisfaction tries, rslists can be nested to produce more complex requirements (and satisfactions). Because rslists, like all atoms, are referenced using their identifiers (which involve hashes), they form a strict DAG without recursive loops.

It is also worth noting that NULL requirements/satisfactions are permitted as members of rslists, as they provide functionality, in addition to avoiding special cases for their exclusion.

As an example of this functionality, consider a group of 150 parties who wish to require a 2/3 majority to validate a successor to a twist. If an rslist consisting only of their individual requirements is constructed where they all have a weight of 2, then 128 satisfactions would be needed to validate the successor instead of the desired 100. On the other hand, if their weights are all set to 3, then only 85 of them are needed to validate a successor. However, including a NULL requirement with a weight of 155, and assigning a weight of 1 to each of the individual requirements, would produce an rslist that controls succession as desired.



6 Hitches

The fundamental unit of rigging is called a *hitch*. A hitch connecting segment A to segment B proves, roughly, that if B hasn't equivocated then A hasn't either.

More precisely, it proves an exclusive relationship between the segment A, the *footline* of the hitch, and the segment B, the *topline* of the hitch. No other hitch can be formed between the oldest twist in A, the *lead* of the hitch, and newest twist in B, the *hoist* of the hitch.

A is therefore *canonical* with respect to B. This provides the mechanism for uniquely selecting a twist's successor. In particular the newest twist in A, the *meet* of the hitch, is the canonical successor of the oldest twist in A, the hitch's lead.

This exclusive relationship is the basis of integrity-at-a-distance, which allows the state of an asset to be managed by an untrusted system, while still maintaining the full integrity of its issuer.

A `hitch` involves 5 twists:

- the *fastener* `hitch.fastener`
- the *lead* `hitch.lead`
- the *meet* `hitch.meet`
- the *hoist* `hitch.hoist`
- the *post* `hitch.post`

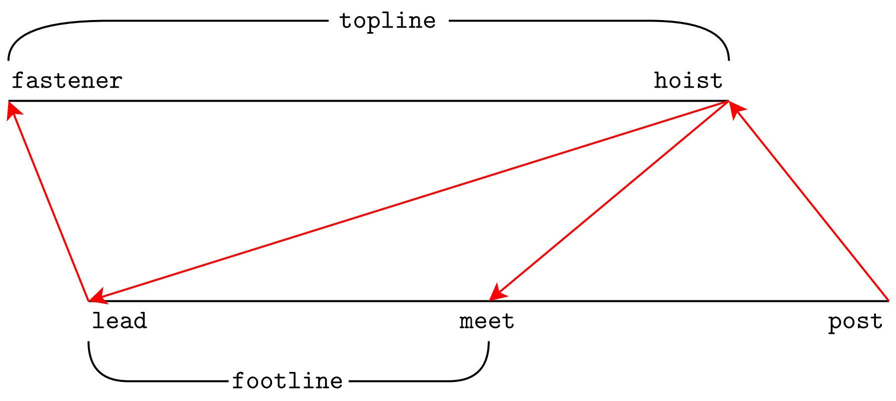
Each position in the hitch has a simple relationship with another, except the hoist, which has a more complicated relationship with several positions.

- `hitch.fastener = hitch.lead.teth`
  The hitch's fastener is defined by its lead.
- `hitch.lead = fastPrev(hitch.meet)`
  The hitch's lead is the first fast predecessor of its meet.[11]
- `hitch.meet = fastPrev(hitch.post)`
  The hitch's meet is the first fast predecessor of its post.
- `hitch.post.rigs[hitch.lead] = hitch.hoist`
  The hitch's post associates its lead and its hoist.
- `hitch.hoist` is the first successor of `hitch.fastener` to hoist `hitch.lead`

The hitch's *topline* is the segment from fastener to hoist:
`hitch.topline = [hitch.fastener, ..., hitch.hoist]`

The hitch's *footline* is the segment from lead to meet:
`hitch.footline = [hitch.lead, ..., hitch.meet]`

A segment `A` is *hitched to* a segment `B` if and only if there is a `hitch` with `hitch.footline = A` and `hitch.topline = B`.



[11] The function `fastPrev` is defined in Section 6.2.

6.1 Hoisting

The heart of a hitch is its hoist. Hoisting a twist binds it to its successor. The hoist of a hitch canonizes `hitch.meet` as the next fast successor of `hitch.lead`[12].

The hoist is the one place that coordination is required between the topline and the footline, as information from the footline must be incorporated into the topline. Otherwise the footline can act entirely independently.

Were the hitch to set the key-value pair $[lead, meet]$ in its rigging trie, this would be sufficient to link the two from the standpoint of the proof structure.

Operationally, however, anyone who knew the lead could post an alternate value, with deleterious effects on the footline. Additionally, anyone who saw $[lead, meet]$ before it was added to the hoist (including the topline operator) could likewise introduce an alternate value.

What is needed is a mechanism that allows values sent to the topline to be accepted *obliviously*. That is, the topline operator should be able to add all received key-value pairs to their rigging trie without introducing the potential for harm. We use the mechanism from [2], which is called *shielding*.

To summarize how shielding is carried out, the footline operator keeps secret the value of the `lead.shld` until the lead gets hitched. This secret value is used in a *shield* function, called S here, which prepends it to an input value, hashes the result into an identifier (using `alg(I(lead))`), and outputs that resulting identifier.

Instead of setting $[lead, meet]$ in the hoist's rigging trie, $[S(lead), meet]$ is set. This prevents other parties from trying to occupy that spot before this key-value pair is sent.

A malicious party who sees the new key $S(lead)$ before it is hoisted could still try to fill it with an alternate value. Therefore a second pair of values is required in the same rigging trie; namely, the shielded versions of the key and its value: $[S(S(lead)), S(meet)]$.

Since only the footline operator knows the secret value, only they can construct this second pair correctly. If the value of the first pair is changed, the value in the second pair will not match. The footline operator can easily prove that the second identifier does not match the hash of the first identifier prepended with their secret, which is a condition for this twist to serve as a valid hoist for the lead.

Once the hoist is constructed then the lead's secret value is incorporated into the rig, in order to prove that the meet is its canonical successor. The atom containing the secret value from the lead of a hitch is normally (only) included in a rigging proof when that rigging proof contains the hoist of the same hitch (i.e. once the lead and meet have been hoisted, and the risk of a bogus meet value getting hoisted has been mitigated).

For a more detailed chronology of the generation, use, and disclosure of the secret value. refer to [2]

[12]Such integrity guarantees are always relative; in this case, to the hitch's topline.

6.1.1 Shield details

We define the *shield function*
`shield(twist, data) = hash(I(twist))(C(twist.shld) | data)`

Recall that `C` takes the content of a packet, so `C(twist.shld)` is `twist.shld` without the initial shape and length bytes. Because shields are only used in hitches, and the shield used in a hitch is that of the hitch's lead, we impose the requirement of being an arb shape on `lead.shld`. Setting it to a shape other than arb results in an issue of INVALID in the lead's status.

Note also that because content length is included as a field in the packet of each atom, and the last shapes in the bitstreams (that are hashed to produced shielded values) are all shapes with constant content lengths (defined in this specification), a length extension attack on these shielding hashes will necessarily render that hashed data invalid.

If `twist.shld` is NULL the above devolves to
`shield(twist, data) = hash(I(twist))(data)`.
Note that zero-length packets are a shape error, so setting `twist.shld` to NULL is the only way to achieve this version.

Shields on loose twists are ignored, and should generally be set to NULL.

Given a particular `hitch`, we define that hitch's shield function `s(hitch)` as
`s(hitch)(data) = shield(hitch.lead, data)`
and require `hitch.hoist.rigs` to contain the following two key-value pairs:

- `hitch.hoist.rigs[S(hitch, I(hitch.lead))] = I(hitch.meet)`
- `hitch.hoist.rigs[S(hitch, S(hitch, I(hitch.lead)))] = S(hitch, I(hitch.meet))`

As indicated in [2], for the functional value of shielding to be properly realized, the shielded key-value pairs used in the hoist cannot have a matching key and value. While this is of limited concern in the hoist itself (because it requires a collision in a cryptographic hash function), it is relevant to the rest of the topline, which is important to the proof.

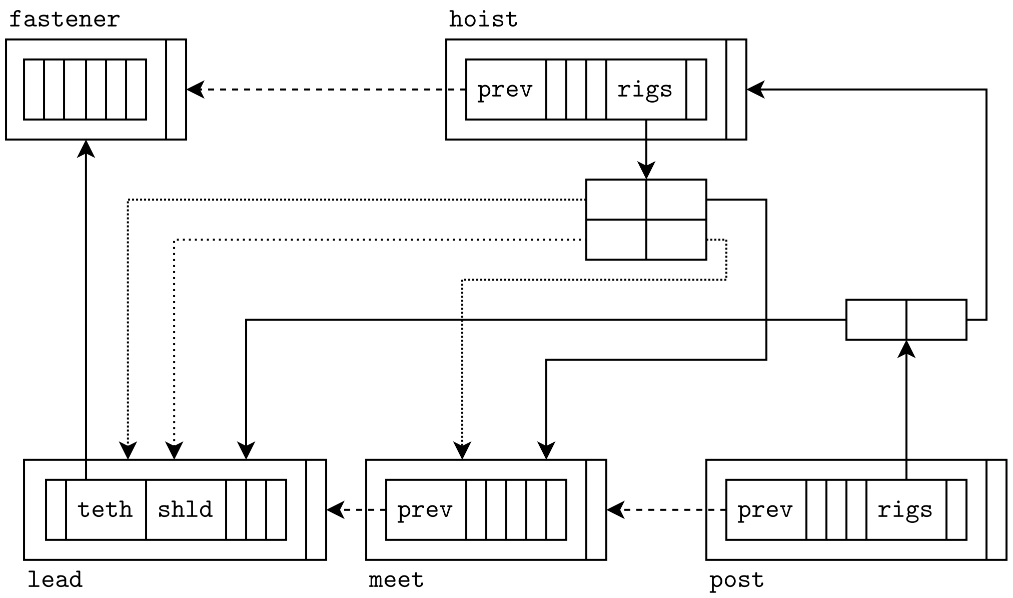
In addition to containing proof that `hitch.hoist` contains those key-value pairs, the hitch must also provide proof that no twist between `hitch.fastener` and `hitch.hoist` contains a pair of entries matching the following description (for arbitrary `data`):

- `twist.rigs[S(hitch, I(hitch.lead))] = data`
- `twist.rigs[S(hitch, S(hitch, I(hitch.lead)))] = S(hitch, data)`
- `twist.rigs[S(hitch, I(hitch.lead))] != S(hitch, I(hitch.lead))`

This proof can consist of proofs of *any* of the following:

- `twist.rigs[S(hitch, I(hitch.lead))]` is not present in the trie,

- `twist.rigs[S(hitch, S(hitch, I(hitch.lead)))]` is not present in the trie,
- `twist.rigs[S(hitch, I(hitch.lead))] = S(hitch, I(hitch.lead))`, OR
- `twist.rigs[S(hitch, S(hitch, I(hitch.lead)))] != S(hitch, twist.rigs[S(hitch, I(hitch.lead))])`



The status objects that describe hitch errors are found in section 9.5.

6.2 Length and Height

A *fast segment*[13] begins and ends with a fast twist (i.e. it has no loose ends). The length of a segment, used in rigging, is defined on fast segments.

To define length formally, we introduce a twist-valued function `fastPrev`, of a twist `t`, which is called the *immediate fast predecessor*:

```
function fastPrev(t)
    if (t == NULL)
        NULL
    else
        if (t.prev.teth != NULL)
            t.prev
        else
            fastPrev(t.prev)
```

[13]In the sense of "fasten", rather than the sense of having a high velocity.

Less formally, the immediate fast predecessor of `t` is the closest predecessor to `t` that is fast (or NULL if `t` has no predecessors that are fast).

With this function and a fast segment `L` (containing n twists), we can now define the length `L.length` of our fast segment to be the value satisfying $\texttt{fastprev}^{\texttt{L.length}}(\texttt{L}[\texttt{n}-1]) == \texttt{L}[0]$ Or more intuitively `L.length` is one less than the number of fast twists in `L` (or the number of sections of fence that can be supported by fenceposts corresponding to the fast twists).

Analogously to a length determining how far away two twists are in time, we also have a height, which determines how far away two lines are in a sort of space, where the unit of distance is a tether. To do this, we introduce a twist-valued function `fastTeth` of a fast twist `t`, which is called the *fast tether*:

```
fastTeth(t) = if (t.teth.teth != 0)
                t.teth
              else
                fastPrev(t.teth)
```

And thus we define the height of the tether from `twist` to `segment`, `height(twist, segment)` to be the smallest n so that $\texttt{fastTeth}^n(\texttt{twist})$ is in `segment`.

7 Rigging

While hitches allow uniqueness of succession in a topline to provide uniqueness of succession in a footline, the tethering must be direct, and the footline's length is limited to 1. In order to allow uniqueness guarantees to be made through indirect tethering, and to provide unique succession for segments with a length greater than 1, we use rigs.

Rigs are assembled from hitches, using rigging operations. A rig `R` is a data structure which includes a *corkline* (`R.corkline`), whose uniqueness of succession enables the rig to prove unique succession in its *leadline* (`R.leadline`). Much like how in normal fishing operations the corkline being buoyed with cork, makes up the top of the net, and the leadline being weighted with lead, makes up the bottom of the net; in a rig consisting of a single hitch, the topline functions as a corkline, and the footline as a leadline. We also identify a rig as having a height `R.height = height(R.leadline[0], R.corkline)`.

A rig is constructed from simpler rigs, using the operations we call *splicing* and *lashing*. The simplest rigs (i.e. the inductive/recursive base case) are half-hitches. A half-hitch has the first four twist of a hitch, but omits the post. Each hitch begins as a half-hitch, before its post is added.

Splicing allows a rig to be extended in time, (which in our diagrams is represented horizontally, and may be referred to as the horizontal direction) by combining it with another rig. Lashing allows a tetherline to extend farther from a desired authority which is represented by a corkline (similar to time being horizontal, this is the vertical direction), and does this by combining it with an additional half-hitch.

Because rigs are used to determine whether a particular line has integrity, it is essential that their correct formation be tested. The status objects that shall describe the results of these tests are described in Section 9.6.

7.1 Splicing

To construct rigs across longer lines a composition operation is required that allows a fast successor to be followed by another fast successor. Note that the meet on a half-hitch is a fast twist and therefore has its own tether, which points to the fastener for a hitch in which it is the lead.

We define this operation, called *splicing*, and use it to construct a rig `splicedRig` whose leadline `splicedRig.leadline` has a length `splicedRig.leadline.length` > 1.

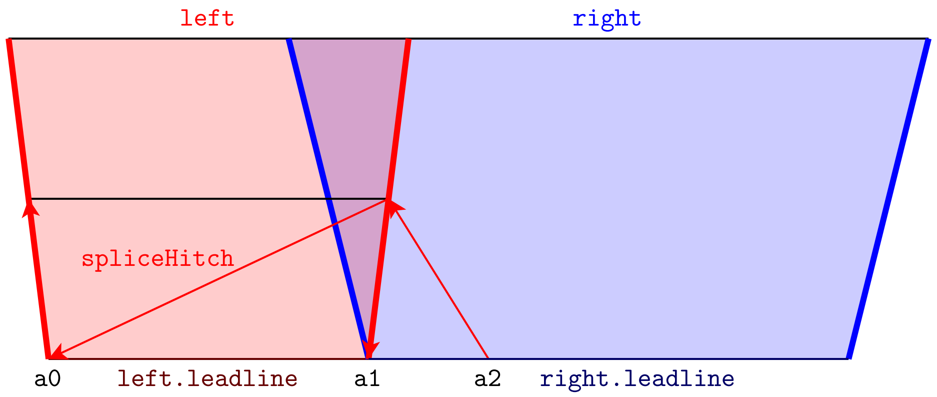
Definition. *If* `left` *is a rig with the following properties:*

- *its leadline has length* `left.leadline.length == 1`
- `left.leadline == [a0, ..., a1]`*, where* `a0` *and* `a1` *are consecutive fast twists, with any number of loose twists between them*
- *there is a hitch* `spliceHitch` *with* `spliceHitch.lead == a0` *and* `splicHitch.meet = a1`

and `right` *is a rig with the following properties:*

- `right.leadline.length == n-1 >= 1`
- `right.leadline == [a1, ..., an]`*, where* `an` *is fast (*`a1` *is the same fast twist as specified in* `left`*)*
- `a2` *(which is possibly equal to* `an`*) is the fast twist in* `right.leadline` *with* `fastPrev(a2) == a1` *(i.e. the first fast twist after* `a1`
- `spliceHitch.post == a2` *(*`spliceHitch` *being the same hitch specified in* `left`*)*

and the corklines `left.corkline` *and* `right.corkline` *of the rigs are aligned then together they constitute a rig* `splicedRig` *that is said to be obtained by splicing* `left` *to* `right` *and whose corkline* `splicedRig.corkline` *is an enveloping segment for* `left.corkline` *and* `right.corkline`*, and whose leadline* `splicedRig.leadline = [a0, ..., an]`*, which is the enveloping line for* `left.leadline` *and* `right.leadline`.



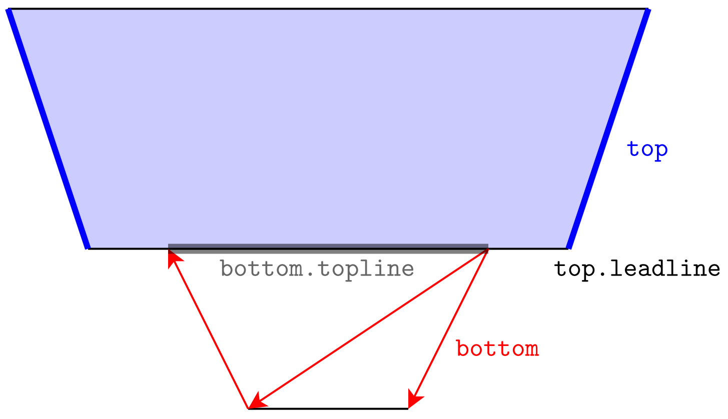
7.2 Lashing

At this point we can now identify arbitrarily many canonical successors along a line, but only if the twists in the line tether directly to the relevant authority. This severely limits the utility of the structures from our guild, so we need to introduce another operation for constructing a rig from simpler rigs. Thus we define the operation of *lashing*.

Definition. *Given:*

- `bottom` *is a half-hitch*
- `top` *is a rig*
- `bottom.topline` *is a subline of* `top.leadline`
- *none of the twists from* `top.corkline` *are present in* `bottom`

then together `bottom` *and* `top` *constitute a rig* `lashedRig`*, that is said to be obtained by lashing* `bottom` *to* `top`*; with a corkline* `lashedRig.corkline = top.corkline`*, and a leadline* `lashedRig.leadline = bottom.footline`*.*



The last requirement (that none of the twists from `top.corkline` are present in `bottom`) may seem a little odd. It is however, necessary for the proofs of the security guarantees provided in [1].

Roughly speaking, this requirement eliminates the possibility of a corkline tethering (likely indirectly) back into itself[14], and introducing the risk that one of the times the corkline is reached, it might support a different leadline than on one of the other times. (This risk seems unlikely to be realized, but impossibility is not yet proven.)

Where this is particularly odd is that this requirement is only imposed on the corkline, and not on any intermediate lines (which are entirely skipped over by the requirement). While a tethering loop can be reached before the corkline in verifying a rig, it being a(n infinite) loop will prevent the corkline from ever being reached, and thus prevent a valid rig with that corkline from ever being constructed.

Consequently, a rig checker should also return a failure upon detection of a tethering loop, regardless of whether or not it involves the corkline (otherwise the checker will very likely crash anyway). This failure shall be identified as a MISMATCH, and be presented in either a lash or splice status object (depending on how the checker traverses rigs, and which operation it was processing when the loop was detected).

The MISMATCH must only be used if there is a provable tether loop. If an implementation avoids following infinite loops by e.g. setting a height limit on rigs, a red error would be inappropriate, and the failure should be identified in a similar object as UNKNOWN.

7.3 Traversal Algorithm

As rig data is provided as a collection of atoms, it is important to be able to reconstruct the structure of the rig from this collection.

[14]When a line tethers to itself, directly or indirectly, we will call that a tethering loop.

This traversal algorithm determines whether the leadline of a rig is supported by its corkline. It is designed to be applied even in cases where the full collection of atoms is not at hand, and must for instance be queried from a database. As such, it takes as its inputs merely the endpoints of the corkline and leadline, also known as the *corners* of the rig.

The inputs expected by this rig traversal algorithm are:

1. a supporting twist (i.e. corkline end) `z_w`
2. a corkline beginning `z_a`
3. a leadline beginning `f_a`
4. a lat associating identifiers to the atoms/packets they identify

In cases where the full set of atoms is known in advance, and are for instance guaranteed to have no equivocal successors, a simpler rig traversal algorithm may be used. Regardless of which algorithm is used, however, all implementations must construct the same rig structure as is constructed by this example algorithm when given the same rig as input.

The example algorithm relies on a store of lines; this store needs to be able to:

1. record a new line from the rig (`linestore.add(newline)`)
2. extend an existing line from the rig by a new line that overlaps or abuts it (`linestore.extend(line, extension)`)
3. indicate whether a specified twist is a member of a line in the store (`linestore.contains(twist)`)
4. for any twist in the store, identify its successor twist in the line containing it (or indicate that it is the most recent twist in that line) (`linestore.getnext(twist)`)

The algorithm (in pseudocode) follows:

```
function construct_line(start, end)
  line = [end]
  curr = end
  while (curr != start)
    curr = curr.prev
    line.append(curr)
  linestore.add(line)

// a function to verify that a line extension is properly supported
// before updating the linestore with it
function extend_line(meet, post, hoist, lead)
  if post.rig[lead] = hoist
    extension = [post]
    curr = post
    while (curr != meet)
      curr = curr.prev
      extension.append(curr)
    linestore.extend(meet, extension)

// returns the most recent fast twist that is
// a predecessor or equal to the argument twist
function active_fast(twist)
  curr = twist
  while (curr.teth == NULL AND curr != FAIL)
    curr = curr.prev
  return curr

// returns the first fast twist that is
// a successor of the argument twist
function next_fast(twist)
  curr = linestore.getnext(twist)
  while (curr != FAIL)
    if (curr.teth != NULL)
      return curr
    curr = linestore.getnext(curr)
  return FAIL

// returns the most recent known fast twist that is
// a successor of the argument twist
function last_fast(twist)
  curr = twist
  next = next_fast(curr)
  while (next != FAIL)
    curr = next
    next = next_fast(curr)
  return curr

// returns the first known successor of fastener with lead as
// a rigging trie key, FAIL if no such successor is known
function find_hoist(fastener, lead)
  curr = linestore.getnext(fastener)
  while (curr != FAIL)
    if (curr.rig.keys contains lead)
      return curr
    curr = linestore.getnext(curr)
  return FAIL

// returns hoist of hitch for which provided twist is lead
function verify_hitch(lead)
```

```
// follow the lead's tether up to the topline/fastener
fastener = lead.teth
// if the topline is already in the linestore, we can try to
// follow it forward to a hoist
if (linestore.contains(fastener))
  hoist = find_hoist(fastener, lead)
  // if the linestore line had a valid hoist,
  // we can return it and are done
  if (hoist != FAIL)
    return hoist
  // otherwise we follow the stored line to its last fast twist
  // and identify it as current
  curr = last_fast(fastener)
  // and set the current twist's fast predecessor as
  // the previous fast twist
  prev = active_fast(curr.prev)
// if the topline isn't already in the linestore,
// we need to move up another level to be able to move forward
else
  // we begin by identifying the lead for the hitch
  // that our fastener is in the footline of
  toplead = active_fast(fastener)
  // and then we use that lead to fill in the hitch
  tophoist = verify_hitch(toplead)
  // with the hitch filled in, we can set its meet as our current twist
  curr = tophoist.rig[toplead]
  // and load this new footline into the linestore
  construct_line(toplead, curr)
  // we check the new footline for the hoist of our original footline
  hoist = find_hoist(toplead, curr)
  // and if it is present, we can return it and are done
  if (hoist != FAIL)
    return hoist
  // otherwise its meet is already set as the current twist,
  // so we set its lead as our previous to continue
  prev = toplead
// having followed the topline for at least one fast twist
// and failed to find a hoist, we continue to extend it forwards,
// one footline at a time, until we find a hoist
while (hoist == FAIL)
  // we set up hoist information to verify proper support
  // of the new segment we're constructing
  // note that this code requires that tophoist is
  // the hoist supporting the last segment of the stored line
  // (the provided pseudocode does not make this the case
  // when extending a stored line)
```

```
    oldhoist = tophoist
    tophoist = verify_hitch(curr)
    next = tophoist.rig[curr]
    extend_line(curr, next, oldhoist, prev)
    // now that the curr-next segment is in the linestore,
    // we check it for the hoist we were originally looking for
    hoist = find_hoist(curr, lead)
    // and advance our previous and current twists, in case it wasn't there
    prev = curr
    curr = next
    // if the hoist was present, the while loop will exit,
    // and we can return it;
    // otherwise we try moving forward again
  return hoist

// returns last successor of f_a that is supported by z_w
function main(f_a, z_a, z_w)
  // set up our corkline
  construct_line(z_a, z_w)
  // find the hoist of the hitch that supports
  // the next fast twist in our leadline
  hoist = verify_hitch(f_a)
  // store the footline of that hitch and
  // get ready to extend it forward
  curr = f_a
  next = hoist.rig[f_a]
  construct_line(f_a, next)
  // keep extending forward as long as we can
  while (hoist != FAIL)
    oldhoist = hoist
    prev = curr
    curr = next
    hoist = verify_hitch(curr)
    if (hoist != FAIL)
      next = hoist.rig[curr]
      extend_line(curr, next, oldhoist, prev)
  // when we can no longer extend forward,
  // return the last twist we reached
  return curr
```

For an example of the steps of this algorithm applied to a rig (with several irregular features which might not be traversed correctly by a poorly implemented traversal function) refer to Appendix B.

8 Commentary

8.1 Error Handling Notes

An invalid atom, for instance one with a packet length that is longer than its content, can cause subsequent atoms to be considered invalid as well, since their offsets will be misaligned. Ensure you check the validity of atoms before you write them.[15]

Up-to-date clients should treat atoms with nospec errors carefully: unlike atomic errors, they are not recoverable by simply re-requesting the information, but unlike shape errors they are not provably broken. Storing them for re-examination after updating the client could result in an exploitable memory leak. They should be discarded and ignored, and proofs that contain them considered broken for most purposes: just not provably broken.

8.2 Evolution and Modularity

Rigging is built using cryptographic primitives which are the subject of ongoing cryptanalysis. Between this cryptanalysis and more general advances in computing, these primitives can be expected over time to lose the properties necessary to support security guarantees. Consequently, it is helpful to point out which parts of this protocol are expected to remain static over time, and which are expected to evolve, so that this information can inform implementation decisions (e.g. around modularity).

The fundamental nature of shapes, packets, identifiers, and atoms is expected to remain static, however new hash algorithms and new shapes are expected to be introduced. Some of these shapes may also be introduced into new class (which may also incorporate existing shapes; e.g. if a novel representation of a twist body is developed, then "twist body" would become a new class of rigging shape, which would incorporate the existing "basic body" shape).

The fundamental role and essential constituents of a twist are expected to remain static (even if new representations emerge), as are previous, next, successor, and predecessor relations, the definition of a line, and the role of a reqsat. The *role* of a reqsat remaining static however, does not preclude the introduction of new types of reqsat (signature type reqsats being an obvious example of a type into which new replacements will need to be introduced, as cryptographic technology progresses, and old signing algorithms cease to be secure).

All of the rigging structures and operations introduced so far (i.e. hitches, rigs, lashing, and splicing) are not expected to change significantly, though the preconditions on the operations (e.g. that no twist in the bottom half-hitch in a lash be present in the corkline of the top rig's corkline) may be relaxed or removed as they are proven unnecessary for the security guarantees a rig provides. Additionally, new operations are expected to be introduced to allow the construction of more diverse rigs (e.g. rigs where the footline of a hitch can support the topline, and these rigs can be combined with each other and with

[15] Particularly if they are being rebroadcast.

existing rigs). No changes to rigging will be made however, which undermine the fundamental rigging guarantee: that any two twists `succA` and `succB` which are supported as successors of the same twist `init` by colinear supports `suppA` and `suppB` will be colinear themselves.

The general model used for verification (i.e. the status objects and their nesting structure) will also remain static, however evolution in other parts of the protocol will have corresponding evolutions in the status objects. (E.g. the introduction of a new type of reqsat will be accompanied by the introduction of status objects for that reqsat type; or the relaxation of preconditions on a rigging operation will be accompanied by the removal or reduction of scope of red statuses for the relaxed condition being unmet).

9 Status Abjects

When presented a list of atoms that do not form the expected rig, it can be difficult to determine what went wrong through manual inspection. Status abjects (using the abjects defined in [3]) provide a way for that information to be communicated in an interoperable form, similar to a stack trace.

9.1 Description

9.1.1 Basics

For each defined structure within a rig, whether it is a concrete structure represented exactly by an atom (e.g. a twist body), or a logical structure composed of multiple concrete structures and the relations between them (e.g. a half-hitch or a reqsat), there is a structure status, which is presented as a DI.

In order to justify a result, it is often necessary for a structure status to refer to the status of subordinate structures, whose status structures are made available as children of the initial status structure. These relationships are described in 9.1.4.

The status abject for the rig then consists of the structure status for the rig itself (which is the focus of the abject). If the rig's structure status (or any other included structure status) has a non-green colour that is determined by its children, then the structure statuses for those children shall also be included.

A structure status DI has the following fields:

`structype`	SYMBOL	indicates the type of structure being checked
`colour`	SYMBOL	indicates the status of the structure (good, bad, or unknown)
`issue`	SYMBOL (OPTIONAL)	indicates the problem with the structure (if there is one)
`children`	TRIE (OPTIONAL)	children of this status abject, as described in Section 9.1.4
`reference`	UNDEFINED (OPTIONAL)	the hash of the specific instance of the structure, whose status is described by this DI

The symbols representing these fields are as follows:

- `structype`
  `0x2299c4857f9cc846feed9155d2df4f25f79f15ecfedaa3ac6ddfa3d102a3c503af`
- `colour`
  `0x2266fccf371f70335ab69bb4157f4a06f3588defddd4493c2490304dc30b80ce18`
- `issue`
  `0x22027072c8fa69e32fa6cb4d6adcbd8d0d5182a186bfbb21d817ffb3039bc6c286`
- `children`
  `0x22bc2d4a3c033b26b15eaa8aafe96fd95370e26779aba66c05b13335ade086ce27`
- `reference`
  `0x2242cb1cadebe0f6d30a7352322580225e50fc1730e222eb5c8eaac068d63f02cc`

9.1.2 Colours

The colour of the focus structure status indicates whether the provided data constitutes a valid rig (green), might constitute a valid rig (yellow), or cannot constitute a valid rig (red). In descendant structure statuses, the colour indicates whether an object is provably good, does not have enough information to prove whether it is good or bad, or is provably bad.

Thus the colours (and the symbols used to represent them) are:

- `green`: proven to be good `0x2224691d8ddb740e9909846dac2cd1356b3328b15583fde539f94b250262edf`
- `yellow`: cannot be proven to be good or bad with the information provided `0x224642657982312fd36471bfb468b650fbc1cadc3c571c079178109f709a41c8a5`
- `red`: proven to be irredeemably bad `0x22ed860e74ea0574b0fd5a275804c00f68ce73a1aa06e22c1ab322f`

The colour of structure status is determined according to the following rules:

1. The status is marked as `green` if the result is not marked with any other colour, and does not inherit a colour from any of its children
2. The status is marked as `red` if the result is marked with a `red` issue (ie. `INVALID`, `MISMATCH`)
3. The status is marked as `yellow` if the result is marked with a `yellow` issue (ie. `MISSING`, `UNKNOWN`) and is not marked with a `red` issue
4. The status inherits the colour of its children using the following rules, if it is not marked with an issue providing colour of its own:
   (a) If the result has been assigned a colour due to any described "Colour Rules", the result's colour does not change
   (b) Else if any of the result's children are marked as 'red', then the result itself is marked as 'red'

    (c) Else if any of the result's children are marked as 'yellow', then the result itself is marked as 'yellow'

5. A rig checker may treat an atomic error as a `yellow` error, and/or a shape error as a `red`, however it may also terminate without providing a status at all on either of these errors.

9.1.3 Issues

Each structure status has a list of potential issues. The order of the list is important: the first issue encountered will be the issue assigned to that status object.
Issues are assigned one of the following types:

- `MISSING`: indicates that a piece of required information was not provided
- `UNKNOWN`: indicates that it was unclear how to interpret a piece of information
- `INVALID`: indicates that the provided information or satisfaction is invalid (e.g., the given satisfaction does not satisfy the given requirement, a given packet has the incorrect shape, etc.)
- `MISMATCH`: indicates that two provided pieces of information do not align

Additionally, atomic errors and shape errors may also be coded as issues, and are given symbols for this purpose. When this is done, these errors take precedence over any status (as they should, since they often render a status impossible to compute).

The symbols used to represent the issues are:

- `MISSING`: `0x22dad0e4311d00c017ea5f8f8304b99bbbc93d798d3d7c0d1af4d0aaae164e843b`
- `UNKNOWN`: `0x222a0ed5cbc7b198a3d088f2c70c6681c8164a90fdd74d9496171b25e08b1eaf78`
- `INVALID`: `0x22c9f630e9dbcb8d55bf4d0bebb6051b5b587863f31fe734404bedfadc012608a4`
- `MISMATCH`: `0x2293ca80267f8eed7ed9d8c8b6a4755c87f91e12d1e52ce0f8a1b946d2b78a7c1b`
- `atomic error`: `0x2223fd016f0a8653cca6e7b679fa69e579ce5fc76443a8c75a7a18551a63d647b8`
- `shape error`: `0x220ad9dd65d2d069c61f8cb9b2c449c3cee145b7f459537feeb8f4b2b4b2defdfe`

9.1.4 Children

Each structure status description includes a list of structure status types which may be present as keys in the `children` trie. Sometimes there are multiple potential children of the same type; in these cases keys are provided in the description of the parent structure status type, and these keys are used instead of the child's type. When a listed status type key is present, the associated value is the identifier of the DI implementing that structure status, which provides the status of the corresponding child object. Any `green` children are omitted from the ‘children‘ trie.

Additionally, some children are given identifiers that end in `[]`. As is convention, this denotes that the child in question is actually a list. Because the children trie is simply a trie, and not a DI with a schema, this list is provided without any abject machinery. The value associated with a key whose identifer has `[]` appended is the identifier for an atom with the `0x61` ”hashes” shape. The identifiers for the child DIs from the lists are then included in that shape in the order described in the child description.

The ‘children‘ trie of a status object should be omitted entirely if:

- The status object itself is `green`
- The status object itself has an issue
- There are no non-`green` children to include

9.1.5 Logical Objects

Logical objects do not have a naturally corresponding atom: for example, a reqsat is a combination of a requirement object and its children with a satisfaction object and its children. Lacking a natural atom from which to draw their identity, they wander the nomenclature wastelands, seeking the solace of an alternative reference wherever it may be found.

9.2 Twist Structure Statuses

These are the results from the checks to ensure that provided twists are consistent with the description in Section 4.

`twist`

`0x221267ca19a66c372b90849cb4f807f6c22b1f36c1057f6bba4f5209b12827beae`

Possible Issues

`MISSING`:	Missing the packet
`INVALID`:	Not a twist

Children

`twist-body`

`twist-body`

`0x2295085430dc7c03412d07e4ff91dd5c2c961cccd6ef910f63a408d6f315e41fa3`

Possible Issues

`MISSING`:	there is no atom available whose identifier matches the body identifier
`INVALID`:	the shape of the body packet is not a twist body shape

9.3 Reqsat Structure Statuses

These are the results from the checks to ensure that provided requirements are satisfied in provided satisfactions in accordance with the description in Section 5.1.

`reqsat`

`0x07b12223bd3d6ce73ed9f70813e7a00d9621326a288540ea53e3a9bf1ce0857e`

Notes

- This is a logical object; there is no "reqsat" atom in the rigging. It has no reference value.
- If the 'reqtrie' child or the 'sattrie' child are non-'green', the other children are not calculated and therefore should be omitted.

Possible Issues

`MISMATCH`	The requirements trie is NULL XOR the satisfactions trie is NULL
`MISMATCH`	The keys in the reqtrie differ from the keys in the sattrie
`UNKNOWN`	A key in the reqtrie and sattrie does not correspond to a known reqsat interpreter

Children

`reqtrie`	A reqtrie structure status
`sattrie`	A sattrie structure status
`rslist-reqsat`	Only present if both tries contain an rslist
`secp256r1-reqsat`	Only present if both tries contain a secp256r1 signature
`ed25519-reqsat`	Only present if both tries contain an ed25519 signature

`reqtrie`

`0x22298f51b6a027ee01e7cc628818018c9e5361aa15ecb2ead84c4c40f15344f8f4`

Possible Issues

`MISSING`	The atom corresponding to the reqtrie identifier was not provided
`INVALID`	The provided reqtrie is neither NULL nor a trie

No Children

`sattrie`

`0x22f05766cc59b6d87d8b81020058b67900bf8195418ba87abe851ee22284da9dfe`

Possible Issues

`MISSING`	The atom corresponding to the sattrie identifier was not provided
`INVALID`	The provided sattrie is neither NULL nor a trie

No Children

9.3.1 List Reqsat Structure Statuses

`rslist-reqsat`

`0x22c9bf129a42fd9478fc42c986ba5b8786675ee42109cd3a9fdba208f4e9654148`

Notes

- This is a logical object; there is no "rslist-reqsat" object in the rigging.
- This object does NOT inheret the colours of its 'rslist-req-entry' children.
- If the 'rslist-req' child or the 'rslist-sat' child are non-'green', the 'rslist-req-entries' child is not calculated and therefore should be omitted.

Special Rules The `rslist-reqsat` object shall be coloured `green` if and only if The total sum of all 'green' rslist-req-entries is ¿= 255.

The `rslist-reqsat` object shall be coloured `yellow` if it shall not be coloured `green`, and

- The sum of weights of all `green` and `yellow` rslist-req-entries is $\geq$ 255, or;
- A `rslist-req-entry` child with a `yellow` `rslist-req-weight` child is non-`red`

Otherwise, the `rslist-reqsat` object shall be coloured as `red`.

Possible Issues

`MISMATCH`	The number of requirements differs from the number of satisfactions

Children

`rslist-req`	
`rslist-sat`	
`rslist-req-entries`	A list of status objects, corresponding to the entries defined in the requirements list. Note that this child is only returned if both other children are green.

`rslist-req`

`0x2241c5142f5ac4cd48cdadd6c11f3c17106b4c7c31b160c241f36b6f65aca45e8e`

Possible Issues

`MISSING`	The atom corresponding to the rslist-req identifier was not provided
`INVALID`	The packet corresponding to the rslist-req identifier does not have hashes as its shape

No Children

`rslist-sat`

`ox2232088b6ba2cfb1a8116b096e5af5eadb1986b2b1b9e168cb17779f2ee48277ea`

Possible Issues

`MISSING`	The atom corresponding to the rslist-sat identifier was not provided
`INVALID`	The packet corresponding to the rslist-sat identifier does not have hashes as its shape

No Children

`rslist-req-entry`

`0x22362e4554299e2ad4e20a13712ada3c23175d129ae0741abdfc2bde7d4165e706`

Possible Issues

`MISSING`	The packet corresponding to this entry was not provided
`INVALID`	The packet corresponding to this entry is not a hashes packet

Children

`rslist-req-weight`
`reqsat`

`rslist-req-weight`

`0x2227f2fbd1e21f73fc5d25f314eeaaa3a693d4083bda1b6cc01135b9d5b54f6517`

Possible Issues

`MISSING`	The packet corresponding to this weight was not provided
`INVALID`	The packet corresponding to this weight is not an arbitrary packet with a 1-byte content

No Children

9.3.2 Signature Reqsat Structure Statuses

`secp256r1-reqsat`

`0x22eabd2839f9e57cf2c372e686e5856cf651d7f07d0d396b3699d1d228b5931945`

Notes

This is a logical object; there is no `secp256r1-reqsat` atom in the rigging. It has no reference.

Possible Issues

`INVALID`	the provided signature is not valid

Children

`secp256r1-req`
`secp256r1-sat`

`secp256r1-req`

`0x2210f601d3262625b2f7ac3d51110f61333755b66d4433261b148aadeaffd75cec`

Possible Issues

`MISSING`	The packet corresponding to this req was not provided
`INVALID`	The packet corresponding to this req is not an arbitrary packet

No Children

`secp256r1-sat`
`0x22fd10613c50d9199489e8f56c723dc09c3cefec00e55a7e93a2fb3f46a1a5f76a`

Possible Issues

`MISSING`	The packet corresponding to this sat was not provided
`INVALID`	The packet corresponding to this sat is not an arbitrary packet

No Children

`ed25519-reqsat`
`0x223d5f4f95cdb1cdfc71014efa1a669fd42599a0ce2000d914a409e48bccaed584`

Notes This is a logical object; there is no “ed25519-reqsat” object in the rigging. This structure status has no reference.

Possible Issues

`INVALID`	the provided signature is not valid

Children
`ed25519-req`
`ed25519-sat`

`ed25519-req`
`0x2261443389b6e2999cd2c25c054be8a11657fb6a06820943bc2cf9229d424c1a12`

Possible Issues

`MISSING`	The packet corresponding to this req was not provided
`INVALID`	The packet corresponding to this req is not an arbitrary packet

No Children

`ed25519-sat`
`0x22b2cfec6188557738125b7e4d41dfd3bd82e38e453aecb747ae9d741d129fa296`

Possible Issues

`MISSING`	The packet corresponding to this sat was not provided
`INVALID`	The packet corresponding to this sat is not an arbitrary packet

No Children

9.4 Line Structure Statuses

These are the results from the checks to ensure that provided lines are consistent with the description in Section 5.

`succession`
`0x227fd8ded12940e8b4d16001ab8bc1b80c55052eadba8bd707a6df766d5f50e3ef`

Notes A succession is a logical object. The ‘successor‘’s twist is used as a reference.

Children

`successor`	A `twist` status object corresponding to the successor
`predecessor`	`twist` status object corresponding to the predecessor
`reqsat`	the `reqsat` for the relation in question (req from predecessor, sat from successor)

`line-segment`

`0x22366a8aa7e49d39bd21eb95cf26c6b6e899d9213b4c80b638c7d352b68c24954e`

Notes This is a logical object. Its reference is the identifier for the most recent (newest) twist in the line-segment. Given a fast twist `start`, we walk backwards until we reach another fast twist

Possible Issues

`INVALID`	the `start` twist is not a fast twist (either a loose twist or a non-twist shape)
`UNKNOWN`	the `start` twist has a shape that has not (yet) been assigned
`MISMATCH`	NULL is reached

Children

`twist`	the twist result for the `start` twist
`succession[]`	A reverse-chronological list of succession objects, starting at a fast twist and ending when it reaches another fast twist. If a succession object is non-green, this list is short-circuited

9.5 Hitch Structure Statuses

These are the results from the checks to ensure that provided hitches are consistent with the description in Section 5.

`hitch`

`0x22d0eb6e7af1ca49d58104b3862955078f2e33a1c67645e15459d6808157fd5c88`

Note

- A hitch is a logical object; its reference is the identifier of its post
- The half-hitch (child) structure status may be returned with an invalid lead-footline before the post-key is calculated

Possible Issues

`MISMATCH`	The terminal twist of the post-footline does not match the meet of the half-hitch, or the post-footline contains a fast twist other than at its endpoints

Children

`post`	
`post-footline`	A `line-segment` object starting at the post
`post-key`	
`half-hitch`	The `half-hitch` object.

`half-hitch`

`0x222008d2f5c875b46e4f52896ecae0c12f686cc43f57409bde83760fe50388b868`

Notes

- The half-hitch is a logical object; its reference is the identifier of its meet
- The half-hitch status may be shortcut in the event that the hitch cannot locate the `lead` (e.g. the `lead-footline` is invalid). In that event, the `lead-footline` will be the only child returned.
- The `fastener` is intentionally omitted as a child; it is a grandchild via the `topline`

Possible Issues

`MISMATCH`	The terminal twist of the lead-footline does not match the lead

Children

`lead`	
`hoist`	
`meet`	
`lead-footline`	A `line-segment` object starting at the meet
`topline`	

`lead`

`0x2288dc9ca034029a13c404ecf210d42698c9971ad78594d72c6e790dc5c4945b2f`

Notes

Because the lead is a twist, its reference is the identifier for the twist which instantiates it.

Possible issues

`INVALID`	The lead's tether has a known non-twist shape, or its shield is something other than an arb or NULL
`MISMATCH`	The hitch being checked has a specified fastener, and the lead's tether is a twist other than that fastener
`UNKNOWN`	The lead's tether has an unrecognized shape
`MISSING`	There is no provided atom whose identifier matches the lead's tether

Children

`twist`

`hoist`

`0x22863bfdc943c67ed29ee7a3e199ac281e93df674809a4a7795317ded106210b30`

Notes

Because the hoist is a twist, its reference is the identifier for the twist which instantiates it.

Possible issues

`MISSING`	there is insufficient trie data to establish whether the provided lead is a key[16]
`INVALID`	the hoist's rigging packet has a non-trie shape
`UNKNOWN`	the hoist's rigging packet has an unassigned shape
`MISMATCH`	the hoist's rigging trie is provably incapable of hoisting the provided lead (i.e. there is a null proof for `shield(lead,I(lead))` or for `shield(lead,(shield(lead,I(lead))));` or `rig[shield(lead,(shield(lead,I(lead)))] !=` `        shield(lead,(rig[shield(lead,I(lead))]));` or `rig[shield(lead,I(lead))] = shield(lead,I(lead)))`

Children

`twist`

`meet`

`0x22a94d1bc7016fb4422f0dab55c9c3800b9b98d70cbbb4198a8bc4bff7c15c9bb8`

Notes

Because the meet is a twist, its reference is the identifier for the twist which instantiates it.

Possible issues

`INVALID`	The meet's tether is NULL

Children

`twist`

`post`

`0x224abe314aa6feb47cdfdc2b07c00c64a2b668f0d9edd4454d95e6c8c01254e73c`

Notes

Because the post is a twist, its reference is the identifier for the twist which instantiates it.

Possible issues

`UNKNOWN`	The post's tether has an unassigned shape
`INVALID`	The post's tether is NULL or has a non-twist, non-UNIT shape

Children

`twist`

`post-key`

`0x227290df7d067bf0608a4785024376d744e50b7c4d285ddd5c3b932e8e78e3ce26`

Notes

This is treated as a logical object. Its reference is the twist identifier for the post whose rigging trie is being examined (i.e. the same reference as the sibling post structure status).

Possible Issues

`MISSING`	there is no atom whose identifier matches post.rigs
`UNKNOWN`	the post's rigging has an unassigned shape
`INVALID`	the post's rigging has a non-trie shape
`MISMATCH`	cannot find the 'lead' in the post's rigging, or the value for that key is not the hoist's identifier

No Children

`topline`

`0x22031c1b1fc93d62b5cac2456f2408a0e4fe6c30560efc82a4270864fbb779e520`

Notes

This is a logical object. Its reference is the hoist for the hitch it is the topline of (which is also its most recent twist).

Possible issues

`MISMATCH`	the provided topline does not include the provided fastener as one of its twists (i.e., NULL is reached)

Children

`succession[]`	A reverse-chronological list of succession objects, starting at the hoist and ending at the successor of the fastener. If a succession object is non-green, this list is short-circuited
`topline-key[]`	A reverse-chronological list of topline-key structure statuses, starting at the predecessor of the hoist and ending at the successor of the fastener.

`topline-key`

`0x22e335eaae9e2cbbf1f1139999dd67c7ad9370a63d30e16a6eb4615d158b459e7b`

Notes

This is treated as a logical object. Its reference is the identifier for the twist (in the topline) whose trie contents are being reported on.

Possible issues

`INVALID`	the rigging shape is a known non-trie, non-NULL shape
`MISMATCH`	the rigging trie provided satisfies the hoist condition for the provided lead
`MISSING`	there is insufficient rigging trie data to establish whether the trie satisfies the hoist condition
`UNKNOWN`	the rigging shape is not a known shape

No Children

9.6 Rigging Structure Statuses

These are the results from the checks to ensure that provided rigging is consistent with the description in Section 7.

Because each rig could be either of: a single half-hitch, the result of a lashing operation, or the result of a splicing operation, the `rig` status object is taken to include all of these things. In particular, one of the operands in the splicing operation (the one whose leadline has a length of 1) must be either a single half-hitch, or the result of a lashing operation. Likewise, one of the operands in the lashing operation muse be a single half-hitch.

Thus our `rig` object is taken to have a `rig` and a `splice` as optional children, which are null if the rig's leadline has a length of 1. The rig supporting the most recent fast segment of the leadline is handled in the remaining objects.

Of these remaining objects, there is another `rig` object, and a `lashing` object, which are also optional (they are null if the most recent fast segment of the leadline is supported by a single half-hitch), and a mandatory `half-hitch` object, which always represents the half-hitch whose footline is the most recent fast segment of the leadline.

`rig`

`0x22d7357365f862a15d5fc6de991334e96c084bbabfcff1150425c9944fb3937a9e`

Notes

- The reference for this structure status is the identifier of the earliest twist on its leadline.

Possible Issues

`INVALID`	The corkline does not support this rig's leadline
`MISMATCH`	The leadline of this rig is not disjoint from its corkline

Children

`corkline`	The corkline specified by arguments to the check
`lash`	
`splice`	This object is only present if this rig is being spliced onto a previous rig
`half-hitch`	The half-hitch whose lead is the earliest twist on the rig's leadline
`hitch`	A hitch object with a post equal to the meet of the half-hitch specified above. This object is only present if there is a splice

`corkline`

`0x222db7e19336b76c355ec281232f9aaad367d4a8544f092e4f147ca5bf7344cd8e`

Notes

This is a logical object. Its reference is the identifier for the most recent twist in the corkline.

Possible Issues

`MISMATCH`	The corkline traversal reached NULL rather than the specified earliest twist

Children

`succession[]`	A list of succession objects in reverse chronological order, starting at the specified end twist

`splice`

`0x22fd2e95961c3986ff20ea8371b2406f24fe893a1faaf7759276c9704c1143aa3c`

Notes

This is a logical object. Its reference is the identifier of the twist in the leadline that is common to the two rigs being spliced.

Possible Issues

`MISMATCH`	The meet of the hitch does not match the meet of the spliced half-hitch
`MISMATCH`	The hoist of the hitch does not match the hoist of the spliced half-hitch
`MISMATCH`	A tether loop was detected while checking the splice
`UNKNOWN`	A tetherline which exceeded the checker's maximum height was detected while checking the splice

Children

`rig`	The rig that is spliced onto the earlier side of the parent rig

`lash`

`0x22586938dc68fa248d582fd7f76adf6f67da179f7baa547e6bc485869545c58d7a`

Notes

This is a logical object. Its reference is the identifier of the meet from the bottom half-hitch.

Possible Issues

`MISMATCH`	A tether loop was detected while checking the lash
`UNKNOWN`	A tetherline which exceeded the checker's maximum height was detected while checking the lash

Children

`rig`	The rig that the sibling half-hitch of this lash structure status is lashed onto (the bottom of)
`fast-tether`	
`lashing-trie`	

`fast-tether`

`0x228b730494b3603f48d0650380107043ec621890db2cc421339f713fb38f126ab9`

Notes

- This is a logical object. Its reference is the (twist) identifier of the lead in the half-hitch (inside the grandparent rig) which is being lashed (via parent lash) up to a (sibling) rig.

- This object verifies the line connecting the tether of the lead just mentioned, to the fast tether of said same lead

Possible Issues

`MISMATCH`	The tether and all its predecessors back to NULL are loose
`MISSING`	A fast tether could not be found from the provided tether and predecessors

Children

`succession[]`	a list of succession objects in reverse chronological order, starting at the fastener of the half-hitch (from the grantparent rig)

`lashing-trie`

`0x22b4cee32aea047c8aa6236bf95e9ad24991e9d57f5c7d6c9a0b0ef2ff662a21bd`

Notes

- This is a logical object. It is referenced by the identifier of the the twist with a missing rigging trie.
- This object ensures that the leadline of the (upper) rig in the lashing has sufficient rigging trie information to properly establish a hoist for the (lower) half-hitch
- The name of this object is subject to change (we don't think it fits our conventions very well, and don't like it).

Possible Issues

`MISSING`	The referenced twist's rigging trie has missing information

A Notation Conventions

A number of data structures are described in this document, as well as functions and relations between them. They are, like code, in the `monospace` font, with camelCase names.

Some relations and expectations are defined by reference to iterated functions. Iteration of functions are denoted by superscripts in the usual manner (i.e. $\texttt{fn}^0(\texttt{obj}) = \texttt{obj}$ and $\texttt{fn}^{n+1}(\texttt{obj}) = \texttt{fn}(\texttt{fn}^n(\texttt{obj}))$).

The term *hash* refers to a cryptographic hash function when used as a verb, unless otherwise specified. When used as a noun, it refers to the result of applying a cryptographic hash function, unless otherwise specified.

The term *trie* is used to refer to Merkle tries, as well as other key-value structures that are equally cryptographically secure, such as the pairtrie structure. Additionally, in a trie `trie`, the value associated with a key `key` is denoted as `trie[key]`.

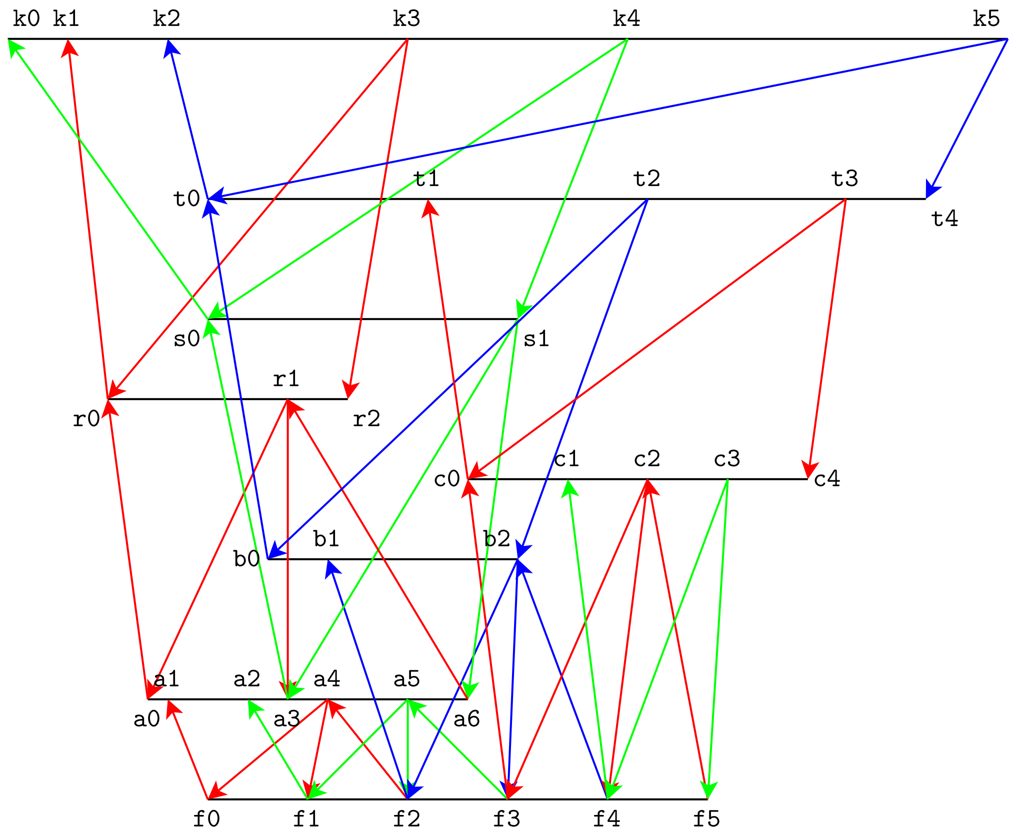
When the value associated with the key in a trie is itself a trie in which a value is being looked up, evaluation is done from left to right – i.e. if `trie[key0]` is itself a trie, then the value associated with the `key1` in that trie is denoted `trie[key0][key1]`.

The notation `a|b` is used to for the concatenation of `a` and `b`, as bytestreams, with `a` preceding `b`.

Constant bytestreams are represented in hexadecimal with a preceding `0x`.

B Rig Traversal Example

In order to demonstrate how the rig traversal algorithm verifies the various components of a rig, the following example has been constructed. It includes an assortment of tether transitions and other such elements that are expected to be relatively commonplace in actual implemented rigs (and a few that are expected to be less common, but nonetheless possible). The line containing the twists whose labels begin with `a` will be referred to as the `A` line, etc. The labelled twists are not intended to constitute all the twists in the rig, however any unlabelled twists (except those in the `K` line are required to be loose.



A rig checker shall be provided with all the the atoms needed to construct this rig, and will additionally take as arguments: the (bottom-left) twist `f0` whose successors are being checked for support, the (bottom-right) twist `f5` whose support as a successor is bring checked, the (top-right) twist `k5` supporting the rig, and the (top-left) twist `k0` which is the oldest corkline twist needed to support the leadline.

The steps to be undertaken by a rig checker following the traversal algorithm provided in Section 7.3 are as follows:

1. The (cork)line `K` is checked (and recorded in the linestore) by following `prev`(s) from `k5` to `k0`.
2. The tether of `f0` is followed to to `a1`.
3. Because `a1` is not on a line in the linestore, it is on a line that still requires support. Further because it is loose, to get this support we follow `prev`(s) until we reach a fast twist `a0`.
4. The tether of `a0` is followed to to `r0`.
5. Because `r0` is not on a line in the linestore, it is on a line that requires support. Further, because it is fast, we can get this support by following its tether to `k1`.
6. Because `k1` is in `K`, we trace forward on `K` until we reach a twist whose rigging trie meets the criteria to hoist `r0`; that twist is `k3`.
7. Having `k3` we can now inspect the half-hitch with `r0` as a lead and `k3` as a hoist. This yields `R` as a footline (which is recorded in the linestore).
8. Because `r0` is on `R` which is now in the linestore, we trace forward on `R` until we reach a twist whose rigging trie meets the criteria to hoist `a0`; that twist is `r1`.
9. Having `r1` we can now inspect the half-hitch with `a0` as a lead and `r1` as a hoist. This yields `A'` (a subline of `A` from `a0` to `a3`) as a footline (which is recorded in the linestore).
10. Because `a1` is on `A'` which is now in the linestore, we trace forward on `A'` until we reach a twist whose rigging trie meets the criteria to hoist `f0` – but `A'` does not contain such a twist, so we continue along `A`.
11. Because `a3` is the most recent twist in `A'`, the tether of `a3` is followed to `s0`.
12. Because `s0` is not on a line in the linestore, it is on a line that still requires support. Further, because it is fast, we can get this support by following its tether to `k0`.
13. Because `k0` is in `K`, we trace forward on `K` until we reach a twist whose rigging trie meets the criteria to hoist `s0`; that twist is `k4`.

14. Having `k4` we can now inspect the half-hitch with `s0` as a lead and `k4` as a hoist. This yields `S` as a footline (which is recorded in the linestore).

15. Because `s0` is on `S` which is now in the linestore, we trace forward on `S` until we reach a twist whose rigging trie meets the criteria to hoist `a3`; that twist is `s1`.

16. Having `s1` we can now inspect the half-hitch with `a3` as a lead and `s1` as a hoist. This yields `A''` (a subline of `A` from `a3` to `a6`) as a footline (which is not yet recorded in the linestore).

17. Because the starting twist of `A''` is the same as the ending twist of `A'` (namely `a3`), we verify the splice of the rigs which meet at `a3` (i.e. those supporting `A'` and `A''`). This includes verifying that `a6` is the post of the hitch with `a0` as a lead. This verification being done, `A'` is extended in the linestore by `A''`, yielding `A` in the linestore.

18. Because `a1` is on `A` which is now in the linestore, we trace forward on `A` until we reach a twist whose rigging trie meets the criteria to hoist `f0`; that twist is `a4`.

19. Having `a4` we can now inspect the half-hitch with `f0` as a lead and `a4` as a hoist. This yields $\mathtt{F}_1$ as a footline (which is recorded in the linestore). The meet of this half-hitch `f1` is not `f5`, so we continue along `F`.

20. Because `f1` is the most recent twist in $\mathtt{F}_1$, the tether of `f1` is followed to `a2`.

21. Because `a2` is on `A` which is in the linestore, we trace forward on `A` until we reach a twist whose rigging trie meets the criteria to hoist `f1`; that twist is `a5`.

22. Having `a5` we can now inspect the half-hitch with `f1` as a lead and `a5` as a hoist. This yields $\mathtt{F}'_2$ as a footline (which is not yet recorded in the linestore).

23. Because the starting twist of $\mathtt{F}'_2$ is the same as the ending twist of $\mathtt{F}_1$ (namely `f1`), we verify the splice of the rigs which meet at `f1` (i.e. those supporting $\mathtt{F}'_2$ and $\mathtt{F}_1$). Thus includes verifying that `f2` is the post of the hitch with `f0` as a lead. This verification being done, $\mathtt{F}_1$ is extended in the linestore by $\mathtt{F}'_2$, yielding $\mathtt{F}_2$ in the linestore.

24. The bottom-right of the verified rig is `f2`, not `f5`, so we continue along `F` and follow the tether from `f2` to `b1`.

25. Because `b1` is not on a line in the linestore, it is on a line that still requires support. Further because it is loose, to get this support we follow `prev`(s) until we reach a fast twist `b0`.

26. The tether of `b0` is followed to to `t0`.

27. Because `t0` is not on a line in the linestore, it is on a line that requires support. Further, because it is fast, we can get this support by following its tether to `k2`.

28. Because `k2` is in `K`, we trace forward on `K` until we reach a twist whose rigging trie meets the criteria to hoist `t0`; that twist is `k5`.

29. Having `k5` we can now inspect the half-hitch with `t0` as a lead and `k5` as a hoist. This yields `T` as a footline (which is recorded in the linestore).

30. Because `t1` is on `T` which is now in the linestore, we trace forward on `T` until we reach a twist whose rigging trie meets the criteria to hoist `b0`; that twist is `t2`.

31. Having `t2` we can now inspect the half-hitch with `b0` as a lead and `t2` as a hoist. This yields `B` as a footline (which is recorded in the linestore).

32. Because `b1` is on `B` which is now in the linestore, we trace forward on `B` until we reach a twist whose rigging trie meets the criteria to hoist `f2`; that twist is `b2`.

33. Having `b2` we can now inspect the half-hitch with `f2` as a lead and `b2` as a hoist. This yields $\mathtt{F}'_3$ as a footline (which is not yet recorded in the linestore).

34. Because the starting twist of $\mathtt{F}'_3$ is the same as the ending twist of $\mathtt{F}_2$ (namely `f2`), we verify the splice of the rigs which meet at `f2` (i.e. those supporting $\mathtt{F}'_3$ and $\mathtt{F}_2$). This includes verifying that `f3` is the post of the hitch with `f1` as a lead. This verification being done, $\mathtt{F}_2$ is extended in the linestore by $\mathtt{F}'_3$, yielding $\mathtt{F}_3$ in the linestore.

35. The bottom-right of the verified rig is `f3`, not `f5`, so we continue along `F` and follow the tether from `f3` to `c0`.

36. Because `c0` is not on a line in the linestore, it is on a line that requires support. Further, because it is fast, we can get this support by following its tether to `t1`.

37. Because `t1` is on `T` which is in the linestore, we trace forward on `T` until we reach a twist whose rigging trie meets the criteria to hoist `c0`; that twist is `t3`.

38. Having `t3` we can now inspect the half-hitch with `c0` as a lead and `t3` as a hoist. This yields `C` as a footline (which is recorded in the linestore).

39. Because `c0` is on `C` which is now in the linestore, we trace forward on `C` until we reach a twist whose rigging trie meets the criteria to hoist `f3`; that twist is `c2`.

40. Having `c2` we can now inspect the half-hitch with `f3` as a lead and `c2` as a hoist. This yields $\texttt{F}'_4$ as a footline (which is not yet recorded in the linestore).

41. Because the starting twist of $\texttt{F}'_4$ is the same as the ending twist of $\texttt{F}_3$ (namely `f3`), we verify the splice of the rigs which meet at `f3` (i.e. those supporting $\texttt{F}'_4$ and $\texttt{F}_3$). Thus includes verifying that `f4` is the post of the hitch with `f2` as a lead. This verification being done, $\texttt{F}_3$ is extended in the linestore by $\texttt{F}'_4$, yielding $\texttt{F}_4$ in the linestore.

42. The bottom-right of the verified rig is `f4`, not `f5`, so we continue slong `F` and follow tether from `f4` to `c1`.

43. Because `c1` is on `C` which is in the linestore, we trace forward on `C` until we reach a twist whose rigging trie meets the criteria to hoist `f4`; that twist is `c3`.

44. Having `c3` we can now inspect the half-hitch with `f4` as a lead and `c3` as a hoist. This yields $\texttt{F}'_5$ as a footline (which is not yet recorded in the linestore).

45. Because the starting twist of $\texttt{F}'_5$ is the same as the ending twist of $\texttt{F}_4$ (namely `f4`), we verify the splice of the rigs which meet at `f4` (i.e. those supporting $\texttt{F}'_5$ and $\texttt{F}_4$). This includes verifying that `f5` is the post of the hitch with `f3` as a lead. This verification being done, $\texttt{F}_4$ is extended in the linestore by $\texttt{F}'_5$, yielding `F` in the linestore, and completing the verification.

C Glossary

In addition to terms and definitions, this glossary includes a symbol for each term. Translations and terminology shifts may change the particular words we use, but these symbols provide canonical nomenclature for the concepts.

arb An atom containing arbitrary binary data
`0x224629c3aada7d7435c0f80430f92313c265dd9f6522e930d9c64dc77d11809866`

atom
An identifier concatenated with its matching packet
`0x228967b176fed39884dc895c6e45bb17c1eb5acf770d9180f6145bff0508c99652`

basic body
A simple body shape containing all twist elements except for the satisfactions
`0x2286dcf3cae43636d736de687478bcb9c8fda275628e759b3685e1ab77d3a0fc40`

basic twist
A simple twist shape containing a body and a satisfactions trie
`0x226d5fbc31b56883513b96fb17ce9476b0c535040890d00eeb565effaa32d7c5c7`

body	Twist element that is not the satisfactions	`0x2295085430dc7c03412d07e4ff91dd5c2c961cccd6ef910f63a408d6f315e41fa3`
cargo	Twist body element containing cargo information	`0x22da124d85769da9ef497178c90666f9b218bfaf529bed80cfbc3ddc0ed0f37eee`
corkline	The line in a rig that provides integrity by supporting the leadline; rhymes with dorkline	`0x222db7e19336b76c355ec281232f9aaad367d4a8544f092e4f147ca5bf7344cd8e`
fast	A fast twist has a non-NULL value for its tether element	`0x2214939b77d4af6d8cbb56599f4b5a0405c02f155da77c5ad801885833623f618a`
fastener	The first twist on the topline of a hitch, and tether of the hitch's lead	`0x2208632db7be34fcb88c72048c3dee66a1de6a9e8b554494bc60a56e94447d58bf`
footline	The line in a hitch containing the lead, meet, and post	`0x221ff39e9e734a7a758e7a8f36187cf3172ca613d3f904e6d3663c856919624aa1`
identifier	A hash algorithm byte, followed by a fixed number of bytes determined by that hash algorithm	`0x2295e1873822a7fbe7eda22b4a895593aaf6ae47645741c3884a21b7c83d810061`
half-hitch	A hitch without the post, and with a footline terminating at the meet; also a minimal rig	`0x222008d2f5c875b46e4f52896ecae0c12f686cc43f57409bde83760fe50388b868`
hitch	Fundamental unit of rigging	`0x22d0eb6e7af1ca49d58104b3862955078f2e33a1c67645e15459d6808157fd5c88`
hoist	The first twist in the topline of a hitch that connects the lead and the meet	`0x22863bfdc943c67ed29ee7a3e199ac281e93df674809a4a7795317ded106210b30`
lash	The result of lashing	`0x22586938dc68fa248d582fd7f76adf6f67da179f7baa547e6bc485869545c58d7a`
lashing	Vertical composition operator for rigs	`0x2234962a88b36217584749c86973c6ad924e58e3b4808287b2e07310ca1b64d47d`
lead	The first fast twist on the footline of a hitch; rhymes with mead	`0x2288dc9ca034029a13c404ecf210d42698c9971ad78594d72c6e790dc5c4945b2f`

leadline
The line in a rig that is gaining integrity by support from the corkline; rhymes with deadline
`0x22c0f2930535e522db887925af31c97d204c94eb059869f53c6a548b100ed6daa8`

line A sequence of successor twists
`0x22366a8aa7e49d39bd21eb95cf26c6b6e899d9213b4c80b638c7d352b68c24954e`

meet The second fast twist on the footline of a hitch; rhymes with meat
`0x22a94d1bc7016fb4422f0dab55c9c3800b9b98d70cbbb4198a8bc4bff7c15c9bb8`

packet
A shape byte and four bytes of length, followed by *length* additional bytes
`0x228ecb044099eab83fbd52b6ddc505b82d57376d1afc7cdb8263146ccf2f6a85eb`

pairtrie
A simple trie shape containing an ordered list of keys and their values
`0x22d9cc0f7b6e15db2cd47642bc32502194ab4737d3eece406e0ebe9320f76677df`

post The third and final fast twist on the footline of a hitch; rhymes with most
`0x224abe314aa6feb47cdfdc2b07c00c64a2b668f0d9edd4454d95e6c8c01254e73c`

predecessor
A twist that precedes another through prev chaining
`0x22b02f4d647e52783e5287a421874f60cf05b2f0de7460366e0f2ec6e464a9ee64`

prev Twist body element containing the previous twist
`0x22158e49e4e6239b1d4649ea36ab7a8cbd0a15ccfb5c26fb5cc313d622894a15d8`

requirements
Twist element that be satisfied by a legitimate successor
`0x2296b985194b1e7ae9034a021c5fbe2a3ab0eb93bfe3375fec28530037ee9d501a`

rig A cryptographic data structure proving the corkline supports the leadline
`0x22d7357365f862a15d5fc6de991334e96c084bbabfcff1150425c9944fb3937a9e`

satisfactions
Twist element that attempts to meet the requirements of its predecessor
`0x22bae131f4c554fdf8a8f0bc6bfe255b6592733c6b13b1e9e3748dce5b3fd6f466`

shape
A byte at the beginning of a packet describing its data structure
`0x22e2b6f5b7b675160d08dea05d32f992c35cf4e219ce9f6f718f14303994b0477e`

shield
Twist body element containing the shield information
`0x22695cc55218f63f312343fe5a43f8bb8bcde964e70dc2370bb495c2f734d56b68`

splice
The result of splicing
`0x22fd2e95961c3986ff20ea8371b2406f24fe893a1faaf7759276c9704c1143aa3c`

splicing
Horizontal composition operation for rigs
`0x228fe955023b969ad90028010fbbd1e43095cfd3e7ce76b87a532d6e6c9101d3f3`

successor
A twist that succeeds another through inverse prev chaining
`0x22292105b6e05dd9eb8d77f276b1af78cd398509089ad43a895d1d7d25c9993673`

support
A line L1 supports L2 when L2 has the same integrity as L1
`0x2292daacaece9550dd3d7eaf51f7fcfad64b327c6bc64763e7148d9a8dab50dac5`

symbol
An atom formed of a single identifier containing 32 arbitrary byes
`0x22274a4d3486b3e29eb56ba22a727d7f39cecbe3d2bca67ca78652d2fa761d17b4`

tether
Twist body element containing the tether twist
`0x220de6828f486f46b3da3a23ec23900e6d7b709d80373015023e775a5438a404c1`

topline
The line in a hitch containing the fastener and the hoist
`0x22031c1b1fc93d62b5cac2456f2408a0e4fe6c30560efc82a4270864fbb779e520`

trie A data type for recording key-value pairs
`0x22b72533ee7c1fee3ef7a39ad923c16b0fe504d39f5271af1e3639ef6e42ccc4d7`

twist An update to a line, a placemoment in spacetime, a name and a now
`0x221267ca19a66c372b90849cb4f807f6c22b1f36c1057f6bba4f5209b12827beae`

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