Systems Architecture for Authentic Data Supply Chains with DAD (Decentralized Autonomic Data) and Zero Trust

Samuel M. Smith Ph.D.
sam@prosapien.com

Authentic Data Supply Chain

Distributed verifiable data structure (signed hash-chained) that provides chain-of-custody (provenance) of the data.

AIDs and signatures link transformation steps.

Changes in control or value or both.

Provides integrity and non-repudiation.

Authentic Data Supply Chain = Provenance

Mechanism for tracing data item content and control (chain-of-custody) through a processing system including any transformations to the data item or its governance.

Includes flows with multiple sources and sinks of data, independently and in combination.

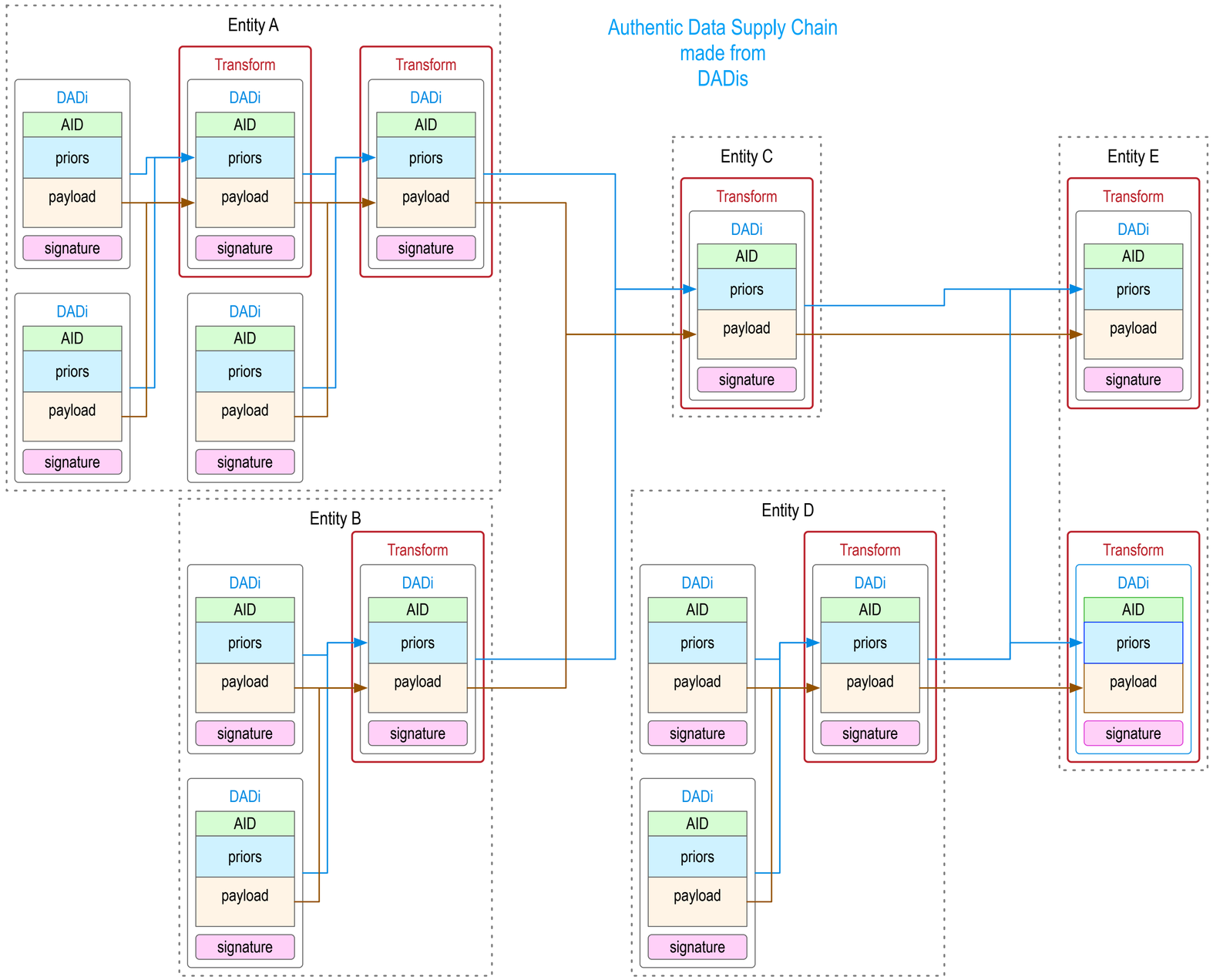
Includes verifying the end-to-end integrity of every data flow including any transformations (additions, deletions, modifications, and combinations).

An entity's influence on an application is solely based on the digital data flows that move between the entity and the other components of the distributed application.

These data flows are the entity's *projection* onto the distributed application.

If those projections consist of *DADis* and every interaction of internal components consists of *DADis* then we have a universal approach for implementing decentralized applications with total provenance of control and data within the application.

ADSC


Authentic Data Supply Chain
made from
DADis
Entity A
Transform
Transform
DADi
AID
priors
payload
signature
Entity B
Entity C
Entity D
Entity E

General Case Architecture: Decentralized Distributed Data Streaming Applications

Decentralized = controlled by multiple entities

Distributed = spread across multiple compute nodes

Establish and maintain provenance (chain-of-custody) for distributed data under decentralized control undergoing various processing stages that follows end-verified perimeter-less diffuse trust (zero-trust) security principles.

Zero-Trust Computing?

Resources:

NIST: Developing a Framework to Improve Critical Infrastructure Cybersecurity 04/08/2013 Zero Trust Model for Information Security, Forrester Research.

http://csrc.nist.gov/cyberframework/rfi_comments/040813_forrester_research.pdf

https://www.nist.gov/cyberframework

Zero Trust Networks 2017 Gilman & Barth

https://www.amazon.com/Zero-Trust-Networks-Building-Untrusted/dp/1491962194/ref=sr_1_1?s=books&ie=UTF8&qid=1499871379&sr=1-1&keywords=zero+trust+networks

Never trust always verify

No such thing truly as *zero* trust

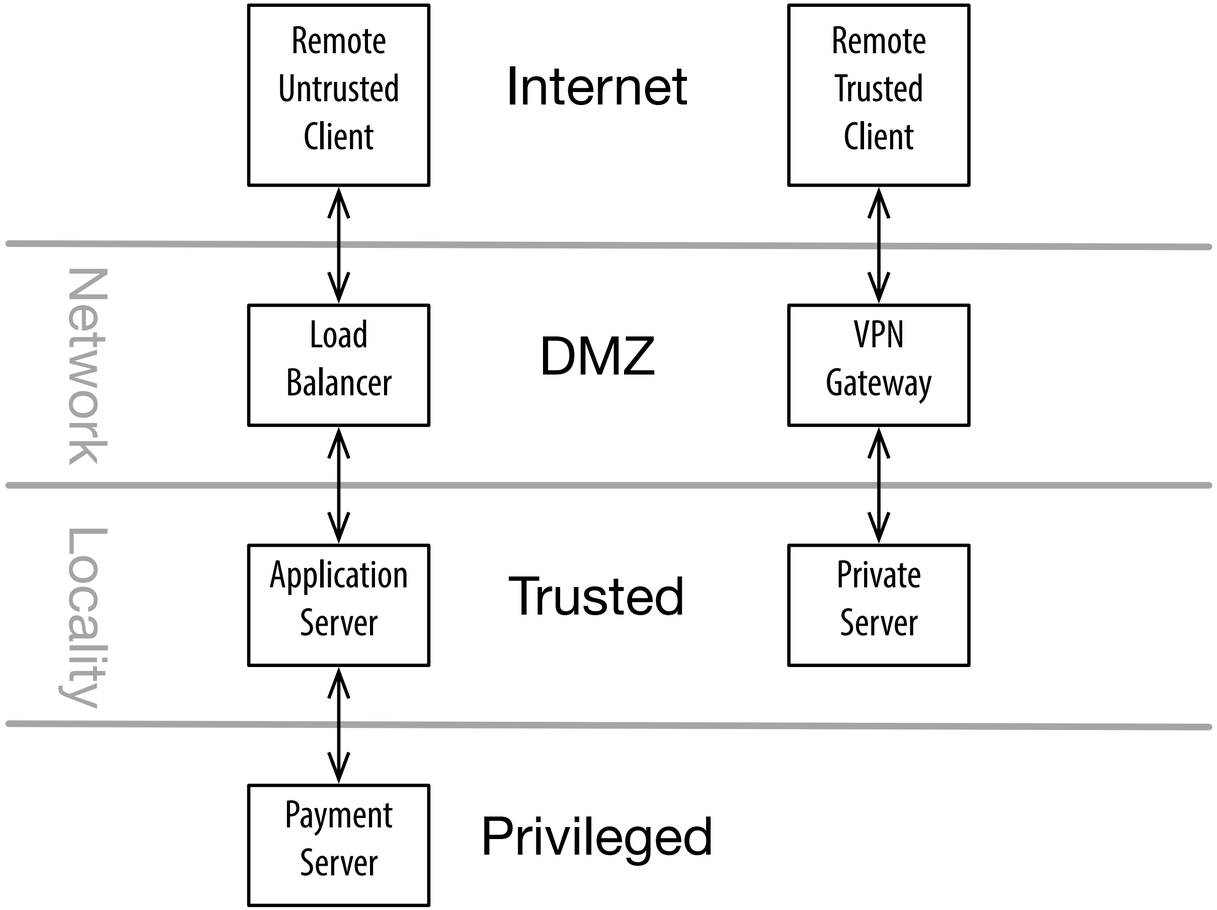
Really composition of *end-verification* and *diffuse* trust

End verified diffuse trust perimeter-less security model (EVDTPL)

Security Models

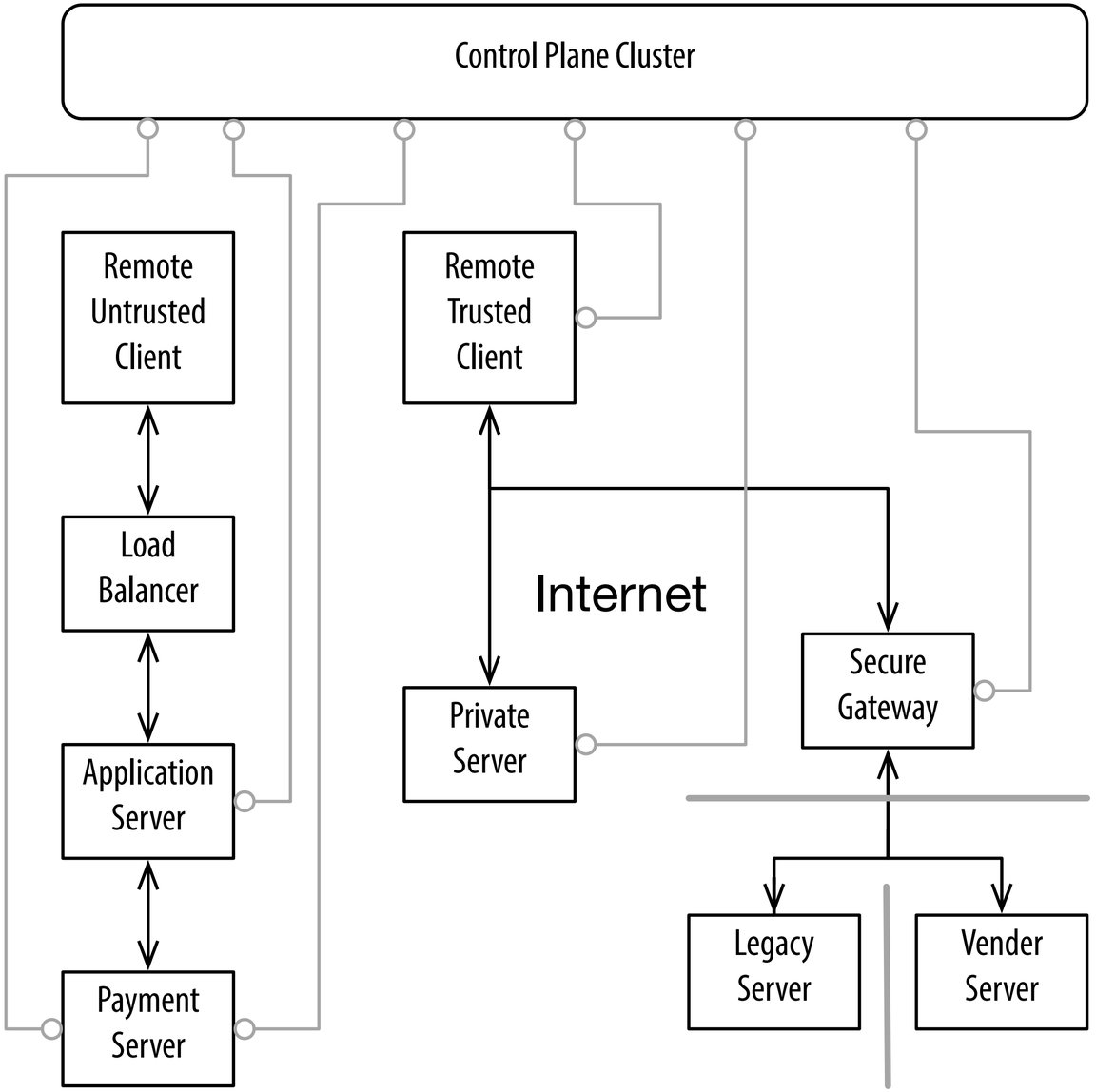
Locality Trust

Hard shells around Soft bodies



Zero Trust

Hard bodies everywhere



Identity Planes and Flows

Control Plane = DKMS (may employ VCs)

Data Plane = Application VCs

Authoritative Control

loci-of-control = *who* controls *what*

Control Statements

Establish and Maintain control over an identifier.

Control over creation or issuance of an identifier. This may include designations of support infrastructure or pre-commitments to future transfers of control.

Control over operations on an identifier.

Control Establishment Operations

Establishment and maintenance of control authority:

Transfer of control (non-revokable).This means transfer of control of the identifier to a different key-pair or set of key-pairs and different signing schemes such as multi-signature *(AKA rotation)*. This may also include transfer designations of support infrastructure. A transfer/rotation operation revokes the current set of key-pairs and replaces them with a new set.

Delegation of identifier (revokable). This creates a new identifier with its own set of keys and authorizes (revokable) some degree of control authority.

Authorization Operations

Communication authorizations:

- Encryption keys
- Routing

Service authorizations:

- Service endpoints

Credential issuance authorizations:

- Delegation

Six diffuse trust perimeter-less security principles

The network is always hostile, internally & externally; Locality is not trustworthy.

Inter-host communication must be end-to-end signed/encrypted and data must be stored signed/encrypted. *Data is signed/encrypted in motion and at rest*.

Data flow transformations must be end-to-end provenanced using verifiable data items (DADis or VCs). *Provenance every change*.

Every network interaction or data flow must be authenticated and authorized using best practice cryptography. *Verify every-time for every-thing*.

Policies for authentication and authorization must be dynamically modified based on behavior (*reputation*). *Authorization is behavioral.*

Policies must be governed by end-verified diffuse-trust distributed consensus. *Policy is protected by diffuse trust*.

Summary end-verifiable diffuse trust perimeter-less security principles

Locality is not trustworthy.

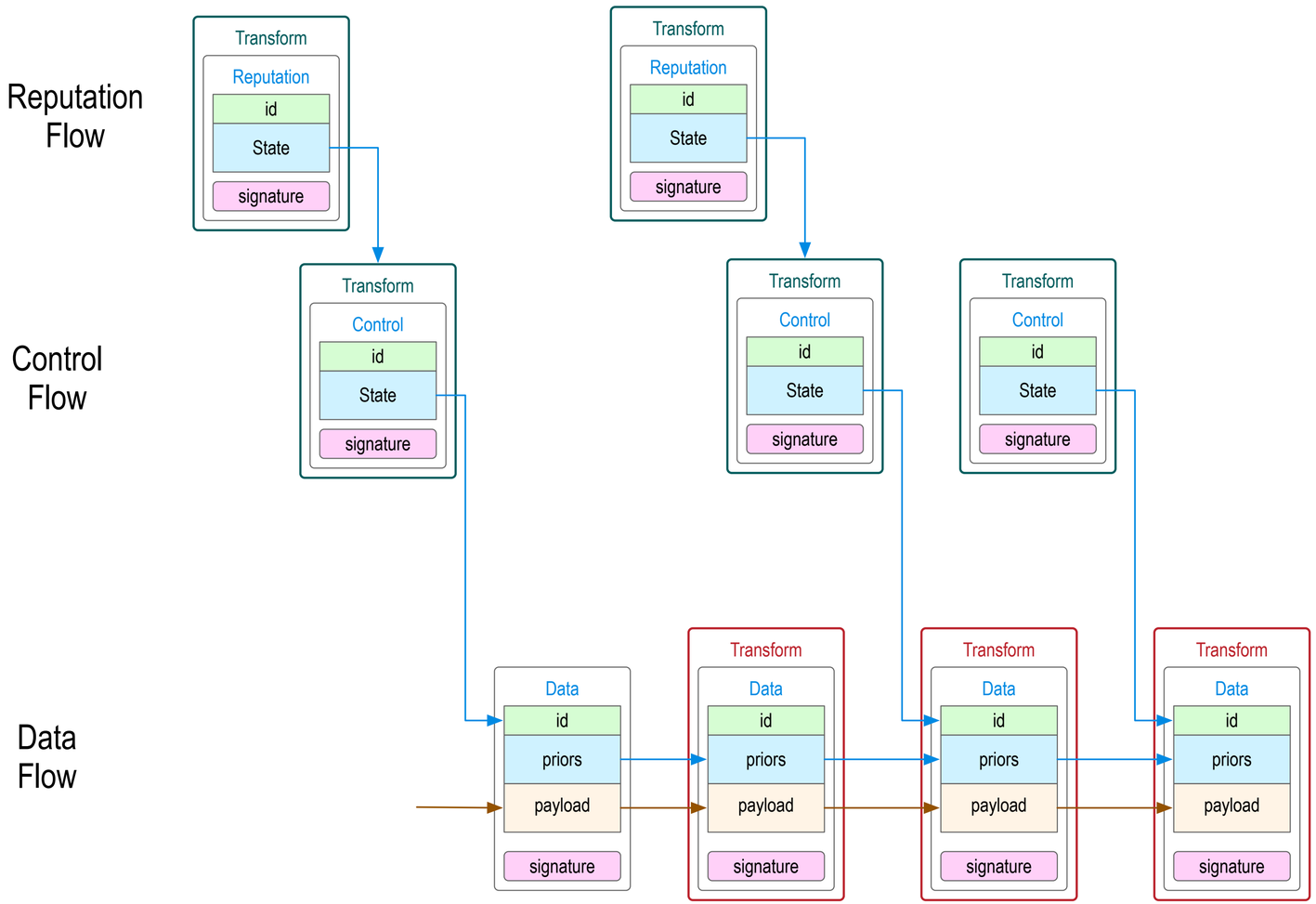
Data is signed/encrypted /provenanced in motion & at rest.

Verify every-time for every-thing.

Authorization is behavioral.

Policy is protected by diffuse trust.

Identity System Layers



Early 2015 began designing decentralized reputation systems with data and algorithm provenance.

https://github.com/SmithSamuelM/Papers/blob/master/whitepapers/open-reputation-low-level-whitepaper.pdf

Needed decentralized identity infrastructure (2016+)

https://github.com/SmithSamuelM/Papers/blob/master/whitepapers/Identity-System-Essentials.pdf

Which led to decentralized identifiers (DIDs) (W3C) (2016+)

https://w3c-ccg.github.io/did-spec/ https://w3c-ccg.github.io/did-primer/

https://identity.foundation (68 Organizations) https://www.hyperledger.org/projects Indy Aries Ursa

Followed by verifiable credentials (VCs) (W3C) (2017+)

https://www.w3.org/TR/vc-data-model/

Combined with zero-trust computing (2017+)

https://github.com/SmithSamuelM/Papers/blob/master/whitepapers/ManyCubed.pdf

Which led to decentralized autonomic data (DAD) (2018+)

https://github.com/SmithSamuelM/Papers/blob/master/whitepapers/DecentralizedAutonomicData.pdf (RWOT6)

Which resulted in data flow chains with data & algorithm provenance (2018+)

https://github.com/SmithSamuelM/Papers/blob/master/whitepapers/A_DID_for_everything.pdf (RWOT7)

Distributed and Decentralized Computing Systems

distributed = computation happens at multiple sites

non-distributed = computation happens at one site

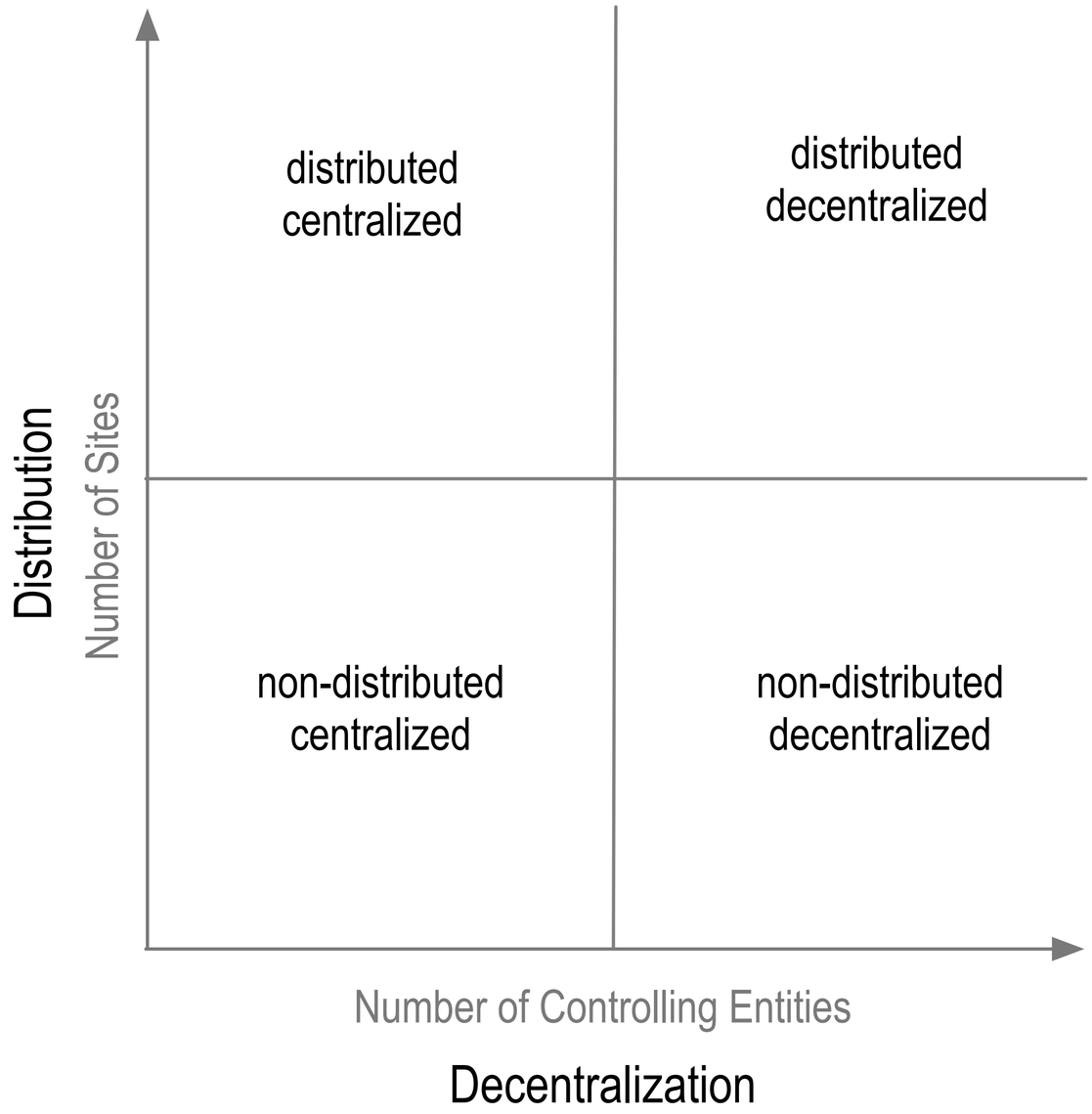
centralized = computation controlled by a single entity

decentralized = computation controlled by more than one entity

computing system may be some combination of *centralized (decentralized)* and distributed (*non-distributed).*

decentralization may occur to a degree.

- system decentralization may lie on a spectrum of strongly decentralized to weakly decentralized.



DID = *UNIFIED* IDENTIFIER

https://w3c-ccg.github.io/did-spec/

did:*method*:*idstring*

did:*dad:Xq5YqaL6L48pf0fu7IUhL0JRaU2_RxFP0AL43wYn148=*

did:dad:Xq5YqaL6L48pf0fu7IUhL0JRaU2_RxFP0AL43wYn148=:blue

did:dad:Xq5YqaL6L48pf0fu7IUhL0JRaU2_RxFP0AL43wYn148=?who=me

did:dad:Xq5YqaL6L48pf0fu7IUhL0JRaU2_RxFP0AL43wYn148=:blue/my/stuff?name=sam#/foo/0

DDo = DID Document. Resolver lookup provides meta-data about DID.

Diffuse trust perimeter-less security principles: 1

The network is always hostile both internally and externally.

Locality is not trustworthy.

Diffuse trust perimeter-less security principles: 2

By default, inter-host communication must be end-to-end signed/encrypted and data must be stored signed/encrypted using best practices cryptography.

Data is signed/encrypted in motion & at rest.

Diffuse trust perimeter-less security principles: 3

By default, every network interaction or data flow must be authenticated and authorized using best practices cryptography.

Verify every time for every thing.

Diffuse trust perimeter-less security principles: 4

By default, each data flow including all transformations must be end-to-end provenanced using decentralized identifiers (DIDs) and hence decentralized autonomic data items (DADis).

Dadify everything.

Diffuse trust perimeter-less security principles: 5

Policies for authentication and authorization must be dynamically modified based on behavior (*reputation*).

Behavioral authorization rules.

Diffuse trust perimeter-less security principles: 6

Policies must be governed by diffuse-trust distributed consensus.

Decentralized control policies.

DID = *UNIFIED* IDENTIFIER: 1

UUID: Universally Unique Identifier RFC 4122:

UUID type 1 -5

'9866eb78-1376-11e9-bab5-58ef68134e82'

16 byte collision resistant decentralized identifier generated with random number generator and optional name spacing data.

Enables distributed applications to create unique identifiers without central authority

Prefixed name spacing allows for sorting and searching properties such as:

time order, lexical order, nesting etc.

DID = *UNIFIED* IDENTIFIER: 2

URI: Uniform Resource Identifier,

URI: Uniform Resource Locator,

URN: Uniform Resource Name

RFC 3986

```
scheme:[//[user[:password]@]host[:port]][/path][?query][#fragment]
```

Enables specifying derived resources from central root.
Mini language for performing operations on resources (ReST).

DID = *UNIFIED* IDENTIFIER: 3

Decentralized Self-Certifying Identifier:

Contains fingerprint of public member of cryptographic public/private key pair.

Key pair is generated by user not central registry.

http://www.sigops.org/ew-history/1998/papers/mazieres.ps 1998

https://pdos.csail.mit.edu/~kaminsky/sfs-http.ps 1999

Enables decentralized self-sovereignty over identifier namespace

Control over namespace proven via signed assertion

Truly portable identifiers

If identifier is not portable then associated data and derived value is not portable

DID = *UNIFIED* IDENTIFIER: 4

Hierarchically Deterministic Derived Self-Certifying Identifier:

selfcertroot:/path/to/related/data?derivation=parent/child/child/child

Enables low friction creation of identifiers on demand without having to store private keys

DID = *UNIFIED* IDENTIFIER: 5

Public lookup services for identifier(s) to find meta-data associated with identifier.

Resolvable identifier meta data. Public decentralized resolvers.

Enables dynamic modification of identifier behavior and control

DID = *UNIFIED* IDENTIFIER: 6

Tupleizable (routable) Identifiers:

/channel/host/process/data = (channel, host, process, data)

Enables data flow routing overlay for distributed data processing systems.

Decentralized Identifiers Invert Compute Architectures

Conventional (centralized):

- Server creates identifiers (GUID, Database primary keys)
- Server timestamps
  - Event ordering relative to server
- Server manages keys,
  - AuthN/AuthZ is indirect via client to server proxy
- Perimeter security around servers
- Server is source of truth
  - Server controls changes/updates to resources
  - Signed at rest problematic
  - Encrypted at rest problematic
- Server's role is 2nd party in two-party transactions between client to server and server to client.

Unconventional (decentralized):

- Client creates identifiers (DIDs)
- Client timestamps
  - Event ordering relative to client or
  - vectorized relative to multiple clients or
  - consensual relative to distributed ledger
- Client manages keys
  - AuthN/AuthZ is direct peer-to-peer
- Perimeter-less security around clients
- Client is source of truth
  - Client controls changes/updates to resources
  - Server cannot make changes
  - Client signs at rest
  - Client encrypts at rest
- Server's role is either:
  - Trusted 3rd party in multi-party transactions between 2 (or more) clients and server as client
  - Agent or proxy for a client in two party transaction with another client.

DAD: Decentralized Autonomic Data

Decentralized: DID based. Governance of the data may reside with multiple parties. Trust in provenance is diffuse.

Autonomic: Self-managing or self-governing. Self-managing includes cryptographic techniques that make the data self-identifying, self-certifying, and self-securing.

Implies the use of cryptographic signatures as the root of trust and to maintain that trust over transformations of that data and its control.

Key management is thus a first order property of DAD.

3-Rs = *Reproduction, Rotation, and Recovery*:

Pre-rotation & Hybrid recovery methods.

Provenance for decentralized distributed data streaming including transformations

DADi: DAD item

Minimally Sufficient Means

Streaming data applications may impose significant performance demands on the processing of the associated data.

Desire efficient mechanisms for providing the autonomic properties of DAD .

DID, DDO, DADi, and dDID

DID = Decentralized Identifier

DDo = DID Document, resolver supplied meta-data about DID.

DADi = Decentralized Autonomic Data Item

Issues:

- Managing meta-data, control, and keys for many DADis
- DDo lookup and caching may be expensive
- DID/DDo pair per DADi may not be practical

dDID (derived DID) = Many unique identifiers derived from one root DID

One *root* DID/DDo provides meta-data for many dDIDs (HD Keychain)

```
did:dad:Xq5YqaL6L48pf0fu7IUhL0JRaU2_RxFP0AL43wYn148=:blue?chain=0/1

did:dad:Qt27fThWoNZsa88VrTkep6H-4HA8tr54sHON1vWl6FE=
```

Reproduction

```
did:dad:Xq5YqaL6L48pf0fu7IUhL0JRaU2_RxFP0AL43wYn148=?chain=0\1\2

did:dad:Qt27fThWoNZsa88VrTkep6H-4HA8tr54sHON1vWl6FE=
```

Simple privacy via unique cryptonym (dDID) per pair-wise relationship

Simple approach to generating large numbers of public dDIDS without having to store the associated private keys.

Only store the root private key

Minimally sufficient relative to more sophisticated methods such as zero knowledge proofs.

dDID Re-Generation

Public Derivation:

Client communicates with large number of public services

dDID is derived from root private key and public service identifier

Client does not need to store dDID but can re-derive on demand

On the fly dDIDs:

Data source is not identified so receiver generates dDID that is later correlated to or claimed by the data source

dDID Management

dDID NameSpacing with HD-path: root + namespace + hd path

```
did:dad:Xq5YqaL6L48pf0fu7IUhL0JRaU2_RxFP0AL43wYn148=:blue?chain=0/1
did:dad:Xq5YqaL6L48pf0fu7IUhL0JRaU2_RxFP0AL43wYn148=:red?chain=0/1
```

dDID Sequencing: dDID + sequence number

```
did:dad:Qt27fThWoNZsa88VrTkep6H-4HA8tr54sHON1vWl6FE=/10057
```

dDID Database

index = anonymous dDID,

value = derivation path from root DID

```
{
   "did:dad:Qt27fThWoNZsa88VrTkep6H-4HA8tr54sHON1vWl6FE=":
   "did:dad:Xq5YqaL6L48pf0fu7IUhL0JRaU2_RxFP0AL43wYn148=?chain=0\1\2",
   ...
}
```

Example Signed DADi


```
{
    "id": "did:dad:Xq5YqaL6L48pf0fu7IUhL0JRaU2_RxFP0AL43wYn148=",
    "data":
    {
        "name": "John Smith",
        "nation": "USA"
    }
}
\r\n\r\n
u72j9aKHgz99f0K8pSkMnyqwvEr_3rpS_z2034L99sTWrMIIJGQPbVuIJ1cupo6cfIf_KCB5ecVRYoFRzAPnAQ==
```

Change Detection

Prevent replay attacks: either or both:

- sequence number in dDID
- *changed* field with monotonically increasing sequence number or date time


```
{
    "id": "did:dad:Qt27fThWoNZsa88VrTkep6H-4HA8tr54sHON1vWl6FE=/10057",
    "changed" : "2000-01-01T00:00:00+00:00",
    "data":
    {
        "temp": 50,
        "time": "12:15:35"
    }
}
\r\n\r\n
u72j9aKHgz99f0K8pSkMnyqwvEr_3rpS_z2034L99sTWrMIIJGQPbVuIJ1cupo6cfIf_KCB5ecVRYoFRzAPnAQ==
```

Entity

Something that has a distinct and independent existence either in the real or the digital world. Examples of an entity are:

Living Organism

Physical Object

Locations or Events

Machines and Devices in the Internet of Things (IoT)

Digital Asset, Data Set or Agent

Chaining up DADi

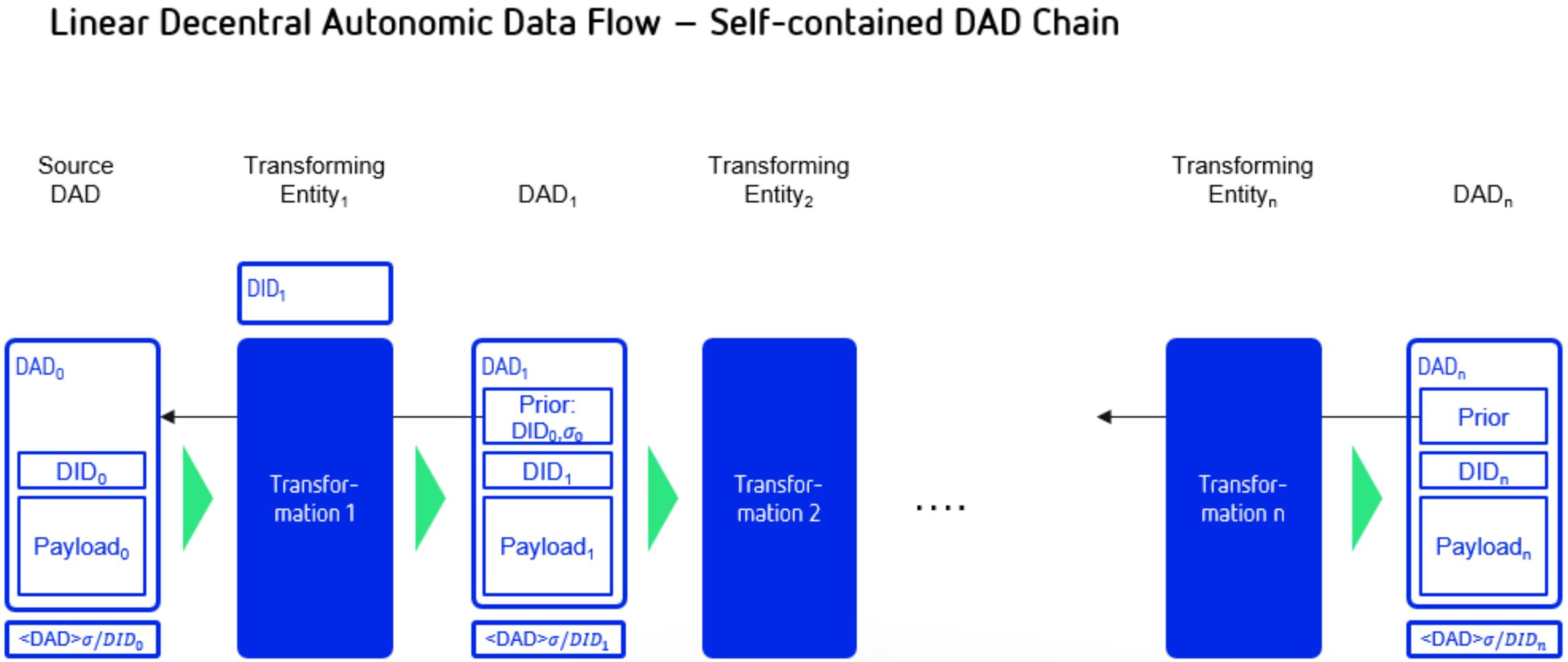
Self-contained virtual blockchain of the data.

IDs and signatures link transformation steps. (control and/or value)

Provides integrity and non-repudiation.

Use associated database to verify complete chain.

Chaining up DADi Diagram Linear

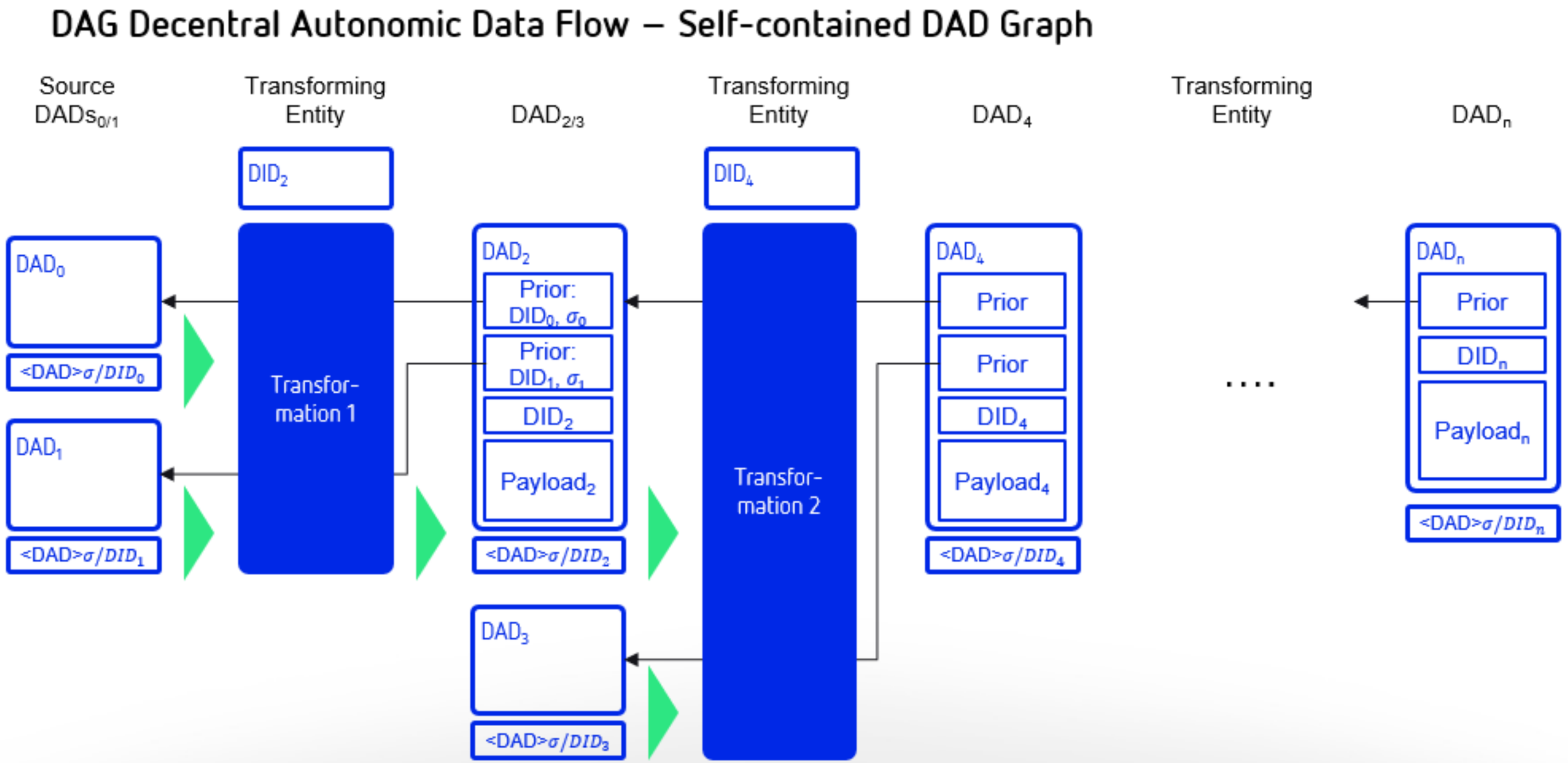


Chaining up DADi Example


```
{
    "id": "did:dad:Qt27fThWoNZsa88VrTkep6H-4HA8tr54sHON1vWl6FE=/alpha/10057",
    "changed" : "2000-01-01T00:00:00+00:00",
    "data":
    {
        "temp": 50,
        "time": "12:15:35"
    }
}\r\n\r\n
u72j9aKHgz99f0K8pSkMnyqwvEr_3rpS_z2034L99sTWrMIIJGQPbVuIJ1cupo6cfIf_KCB5ecVRYoFRzAPnAQ==
{
    "id": "did:dad:AbC7fThWoNZsa88VrTkep6H-4HA8tr54sHON1vWl6FE=/beta/10057",
    "changed" : "2000-01-01T00:00:02+00:00",
    "data":
    {
        "temp": 50,
        "humid": 87,
        "time": "12:15:37"
           }
 "prior",
         {
                "id":  "did:dad:Qt27fThWoNZsa88VrTkep6H-4HA8tr54sHON1vWl6FE=/alpha/10057",
               "sig": u72j9aKHgz99f0K8pSkMnyqwvEr_3rpS_z2034L99sTWrMIIJGQPbVuIJ1cupo6cfIf_KCB5ecVRYoFRzAPnAQ==

}\r\n\r\n
wbcj9aKHgz99f0K8pSkMnyqwvEr_3rpS_z2034L99sTWrMIIJGQPbVuIJ1cupo6cfIf_KCB5ecVRYoFRzAPnAQ==
```

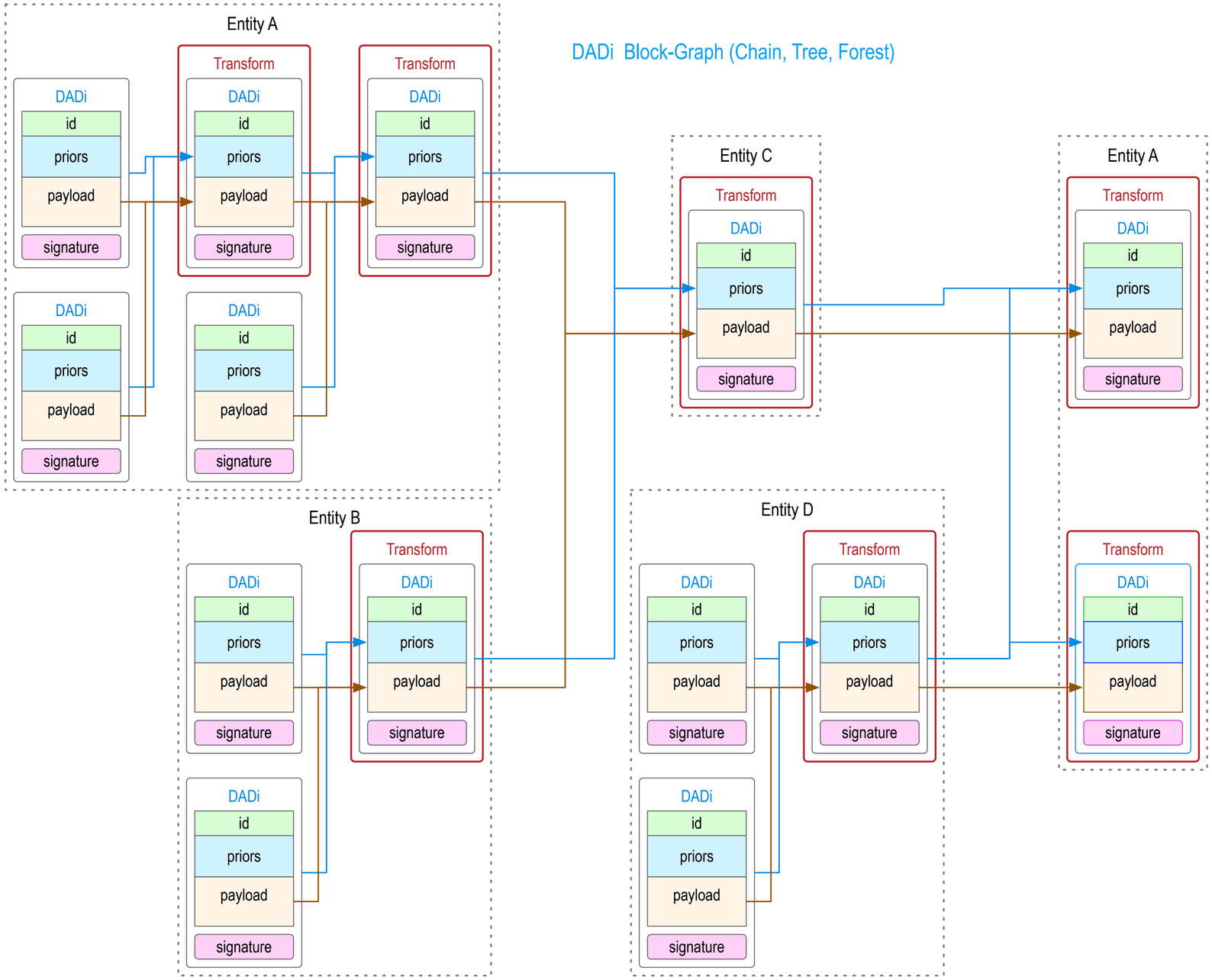
Chaining up DADi Diagram Multiplex



Chaining up DADi Example Multiplex

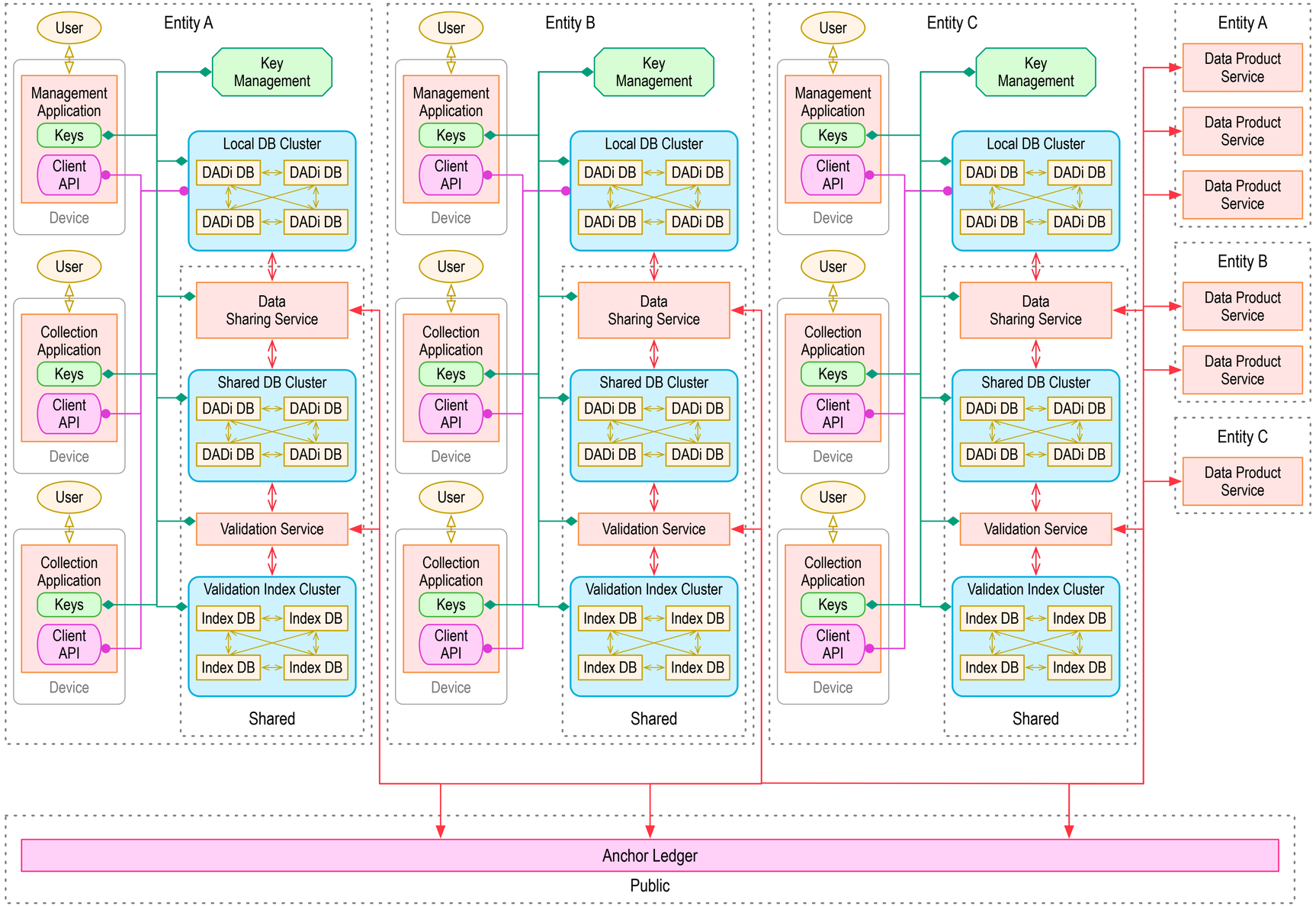

```
{
    "id": "did:dad:AbC7fThWoNZsa88VrTkep6H-4HA8tr54sHON1vWl6FE=/gamma/10057",
    "changed" : "2000-01-01T00:00:03+00:00",
    "data":
    {
        "Avg temp": 55,
        "time": "12:15:39"
  }
      "priors",
         [
           {
                "id":  "did:dad:Qt27fThWoNZsa88VrTkep6H-4HA8tr54sHON1vWl6FE=/alpha/10057",
               "sig":
u72j9aKHgz99f0K8pSkMnyqwvEr_3rpS_z2034L99sTWrMIIJGQPbVuIJ1cupo6cfIf_KCB5ecVRYoFRzAPnAQ==
      },
{
                "id":  "did:dad:WA27fThWoNZsa88VrTkep6H-4HA8tr54sHON1vWl6FE=/beta/10058",
               "sig":
j78j9aKHgz99f0K8pSkMnyqwvEr_3rpS_z2034L99sTWrMIIJGQPbVuIJ1cupo6cfIf_KCB5ecVRYoFRzAPnAQ==
      },
]
}\r\n\r\n
dy3j9aKHgz99f0K8pSkMnyqwvEr_3rpS_z2034L99sTWrMIIJGQPbVuIJ1cupo6cfIf_KCB5ecVRYoFRzAPnAQ==
```

Chaining up DADi Block Graph



Chaining up DADi Architecture

Decentralized Data Chain-of-Custody Architecture



Conclusion & Discussion

sam@samuelsmith.org
https://github.com/SmithSamuelM/Papers
@SamuelMSmith

Dependency Inversion Principle

Dependency Inversion Principle, Martin 1996

Bad Software Design: Software that fulfills its requirements but exhibits any or all of:

Rigidity: Hard to change because each change affects other parts of the system.

Fragility: Making a change causes other parts of the system to break.

Immobility: Hard to disentangle in order to reuse in another application.

DIP:

HIGH LEVEL MODULES SHOULD NOT DEPEND UPON LOW LEVEL MODULES.

BOTH SHOULD DEPEND UPON ABSTRACTIONS.

ABSTRACTIONS SHOULD NOT DEPEND UPON DETAILS.

DETAILS SHOULD DEPEND UPON ABSTRACTIONS.

Its all about dependency management, duh !!!

Dependency Inversion Principle Transcendence

Bad Software Design: Software that fulfills its requirements but exhibits any or all of:

Rigidity: Hard to change because each change affects other parts of the system.

Fragility: Making a change causes other parts of the system to break.

Immobility: Hard to disentangle in order to reuse in another application.

Flow Based DAD transcends the DIP thusly:

THERE ARE NO MODULES, JUST COMPONENTS

THERE ARE NO ABSTRACTIONS OR DETAILS JUST DATA

COMPONENTS DEPEND ON DATA, NOT OTHER COMPONENTS