Advanced Energy System Design (AESD):  
Technical Manual for the Records API

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Table of Contents

[Abstract 1](#_Toc488137542)

[Overview 2](#_Toc488137543)

[Use Cases 4](#_Toc488137544)

[Static Data 4](#_Toc488137545)

[Dynamic Data 8](#_Toc488137546)

[Simulations 10](#_Toc488137547)

[Bookmarks 11](#_Toc488137548)

[Filtering 13](#_Toc488137549)

[Records API, Version 4 14](#_Toc488137550)

[Message Groups 14](#_Toc488137551)

[General conventions 15](#_Toc488137552)

[Messages 16](#_Toc488137553)

[Scalar Value Types 27](#_Toc488137554)

[Appendices 28](#_Toc488137555)

[Protocol Buffers for Records API Version 4 28](#_Toc488137556)

[References 33](#_Toc488137557)

# Abstract

The Records API (application program interface) for Advanced Energy System Design (AESD) enables software that serves multidimensional record-oriented data to interoperate with software than uses such data. In the context of the Records API, multidimensional data records are simply tuples of real numbers, integers, and character strings, where each data value is tagged by a variable name, according to a pre-defined schema, and each record is assigned a unique integer identifier. Conceptually, these records are isomorphic to rows in a relational database, JSON objects, or key-value maps. Records servers might supply static datasets, sensor measurements that periodically update as new telemetry become available, or the results of simulations as the simulations generate new output. Records client software might display or analyze the data, but in the case of simulations the client request the creation of new ensembles for specified input parameters. It is also possible to chain records clients and servers together so that a client consuming data from a server might transform that data and serve it to further clients.

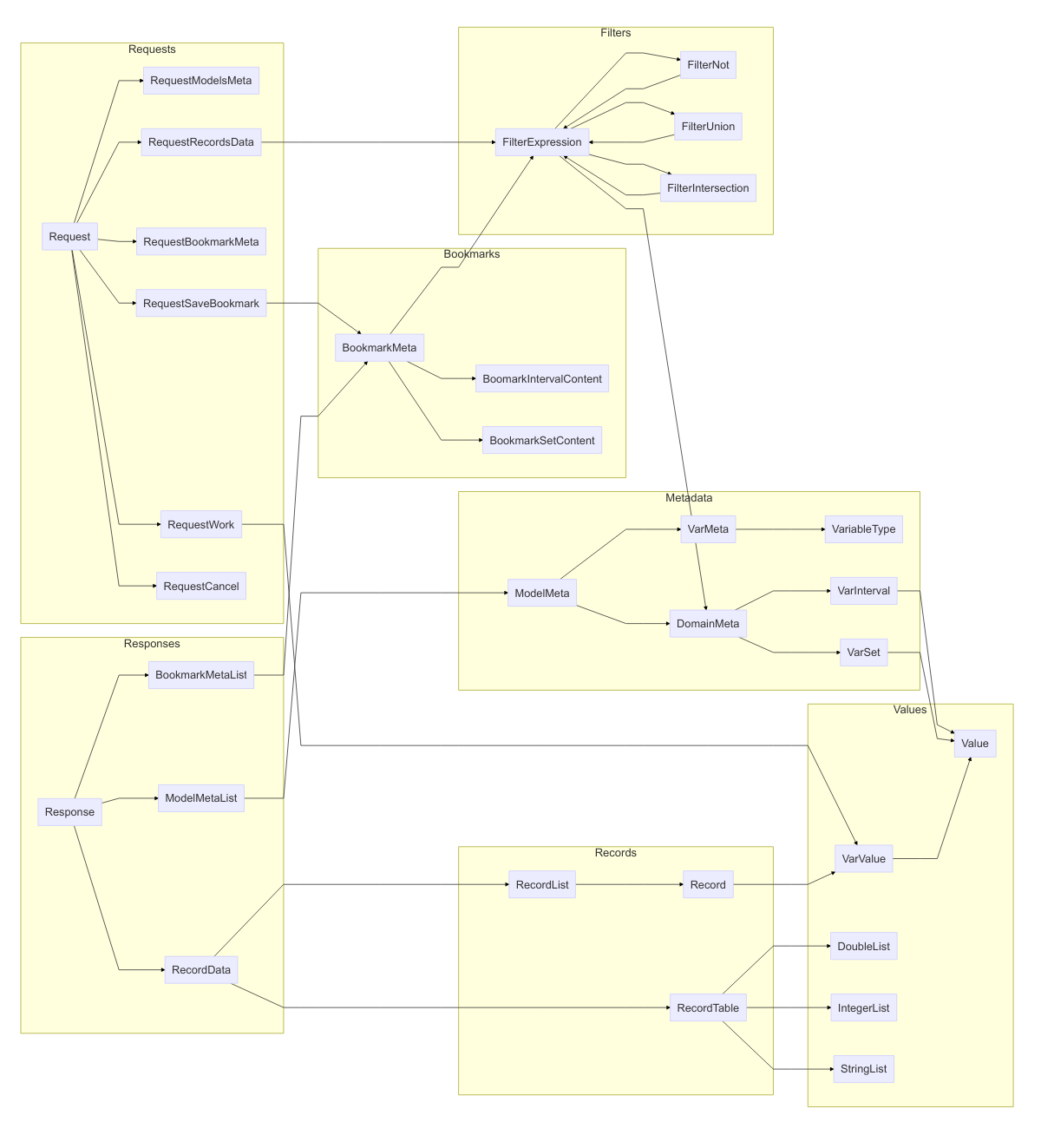
This minimalist API avoids imposing burdensome metadata, structural, or implementation requirements on developers by relying on open-source technologies that is readily available for common programming languages. In particular, the API has been designed to place the smallest possible burden on services that provide data. This document defines the message format for the Records API, a transport mechanism for communicating the data, and semantics for interpreting it. The message format is specified as Google Protocol Buffers (Google Developers 2017b) and the transport mechanism uses WebSockets (Internet Engineering Task Force 2017). We discuss three major use cases for serving and consuming records data: (i) static data, (ii) dynamically augmented data, (iii) on-demand simulations, (iv) with filters, and (v) with bookmarks. Separate implementations of the API exist in C++, Haskell, JavaScript, Python, and R.

# Overview

Client-server communication in the Records API simply consists of clients sending [Request](#EsdaRecords.Request) messages to the server and servers asynchronously sending [Response](#EsdaRecords.Response) messages to the client. The [request and response messages](#requests-and-responses) hold the specifics of the request or response and the responses are correlated with the requests, but it is important to note that multiple responses may occur for a single request, as when record data is chunked into multiple response, or that an error response may be sent at any time. The nested messages within Request and Response may in turn contain nested fields and messages providing further details. The table below shows the correspondence between requests and responses, while the figure following that shows the containment relationships between message types.

Correlation between requests and responses.

|  |  |
| --- | --- |
| Request Field | Response Field |
| [models\_metadata](#EsdaRecords.RequestModelsMeta) | [models](#EsdaRecords.ModelMetaList) or error |
| [records\_data](#EsdaRecords.RequestRecordsData) | [data](#EsdaRecords.RecordData) or error |
| [bookmark\_meta](#EsdaRecords.RequestBookmarkMeta) | [bookmarks](#EsdaRecords.BookmarkMetaList) or error |
| [save\_bookmark](#EsdaRecords.RequestSaveBookmark) | [bookmarks](#EsdaRecords.BookmarkMetaList) or error |
| [cancel](#EsdaRecords.RequestCancel) | no response or error |
| [work](#EsdaRecords.RequestWork) | [data](#EsdaRecords.RecordData) or error |



Containment relationships between protocol buffer messages in the AESD Records API.

[Metadata messages](#metadata) describe “models”, which are just sources of data, and the variables they contain. [Data record messages](#data-records) hold the data itself. Data records are simply tuples of real numbers, integers, and character strings, where each data value is tagged by a variable name, according to a pre-defined schema, and each record is assigned a unique integer identifier. Conceptually, these records are isomorphic to rows in a relational database, JSON objects, or key-value maps. For efficiency and compactness, [RecordData](#EsdaRecords.RecordData) may be provided in [list format](#EsdaRecords.RecordList) or [tabular format](#EsdaRecords.RecordTable), with the latter format only obtained when the contents of the table all have the same data type. The data records may be provided *in toto* or filtered using [filter messages](#filtering) so that only certain fields or records are returned. The API contains a small embedded language for [filtering via set and value operations](#EsdaRecords.FilterExpression). Sets of records may be [bookmarked](#bookmarks) for sharing or later retrieval by (i) enumerating their unique record identifiers, (ii) defining a range of unique record identifiers, or (iii) specifying a filtering criterion.

Servers that perform computations or simulations can receive input parameters via a [RequestWork](#EsdaRecords.RequestWork) message that contains those input parameters. After the server has completed its computations, it sends the results as [RecordData](#EsdaRecords.RecordData) messages.

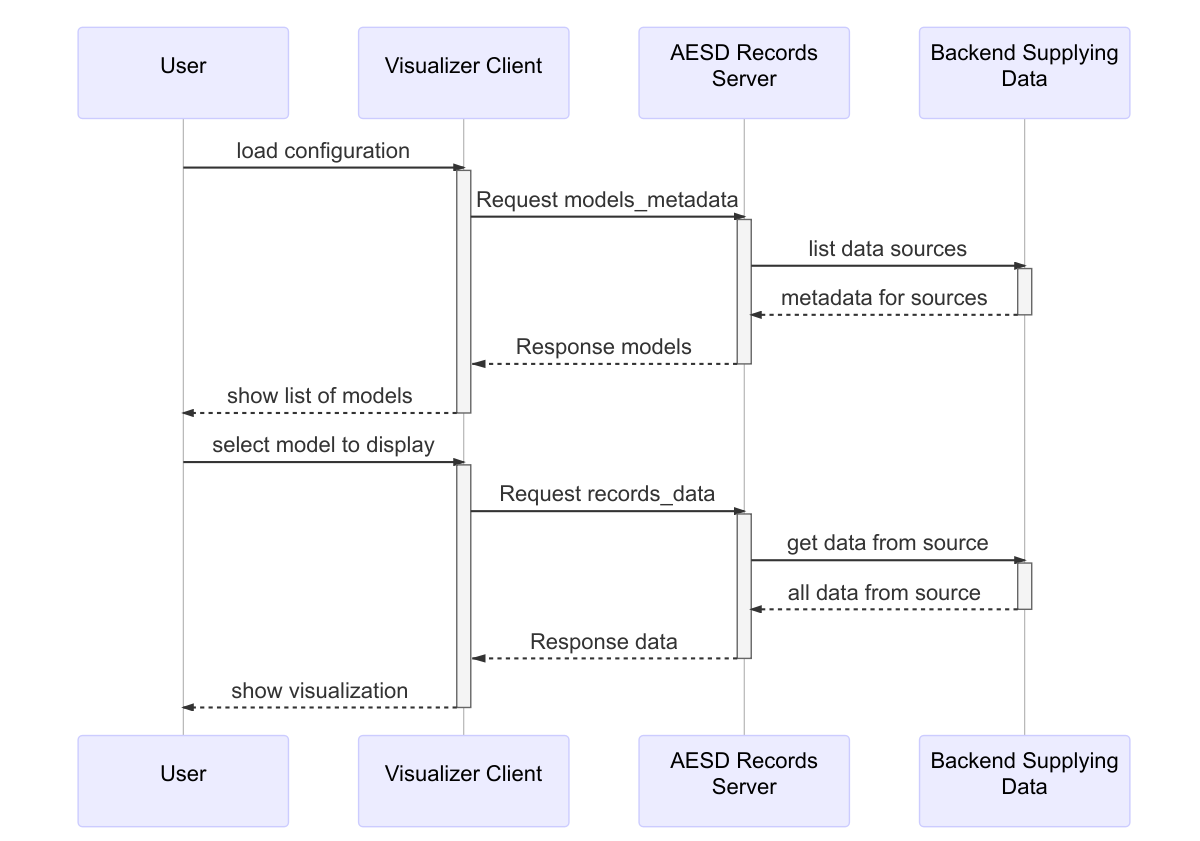
In general the response to a request for data records comes in *chunks* numbered in sequence, where each chunk has an identifier, chunk\_id, and specifies the identifier of the next chunk, next\_chunk\_id. Thus, the chunks form a linked list. The sending of additional chunks can be cancelled using a [RequestCancel](#EsdaRecords.RequestCancel) message. If the [subscribe](#EsdaRecords.Request) flag is set when making a request, then the server will respond indefinitely with additional data as the data becomes available, until the subscription is [cancelled](#EsdaRecords.RequestCancel).

# Use Cases

In this section we outline some standard use cases for the Records API. UML Sequence Diagrams (Fowler 2017) illustrate the flow of messages and the messages themselves are printed in the text format output by the Google protoc tool (Google Developers 2017a).

## Static Data

The retrieval of static data records forms the simplest use case for the Records API. A user chooses a particular data source (a “model” in the parlance of the Records API) and then the data is retrieved and displayed. The visualization client software communicates with a Records server, which in turn accesses the static data. The figure below illustrates the process.



Visualizing data from a static source using the AESD Records API.

A [Request](#EsdaRecords.Request) without model\_id specified requests the server to list all models:

version: 4  
id: 1  
models\_metadata {  
}

The [Response](#EsdaRecords.Response) from the server provides metadata for all of the models:

version: 4  
id: 1  
models {  
 models {  
 model\_id: "example-model-1"  
 model\_name: "Example Model #1"  
 model\_uri: "http://esda.nrel.gov/examples/model-1"  
 variables {  
 var\_id: 0  
 var\_name: "Example Real Variable"  
 type: REAL  
 }  
 variables {  
 var\_id: 1  
 var\_name: "Example Integer Variable"  
 type: INTEGER  
 }  
 variables {  
 var\_id: 2  
 var\_name: "Example String Variable"  
 type: STRING  
 }  
 models {  
 model\_id: "example-model-2"  
 model\_name: "Example Model #2"  
 model\_uri: "http://esda.nrel.gov/examples/model-2"  
 variables {  
 var\_id: 0  
 var\_name: "POSIX Epoch"  
 type: INTEGER  
 }  
 variables {  
 var\_id: 1  
 var\_name: "Measurement"  
 type: REAL  
 }  
 }  
 models {  
 model\_id: "example-simulation-3"  
 model\_name: "Example Simulation #3"  
 model\_uri: "http://esda.nrel.gov/examples/simulation-3"  
 variables {  
 var\_id: 0  
 var\_name: "Input"  
 type: REAL  
 }  
 variables {  
 var\_id: 1  
 var\_name: "Time"  
 type: REAL  
 }  
 variables {  
 var\_id: 2  
 var\_name: "Value"  
 type: REAL  
 }  
 inputs {  
 var\_id: 0  
 interval {  
 first\_value: 0  
 second\_value: 100  
 }  
 }  
 }  
}

Note that the response above is tagged with the same id as the request: this allows the client to correlate responses with the particular requests it makes. Next the user might request three records from the first model:

version: 4  
id: 2  
records\_data {  
 model\_id: "example-model-1"  
 max\_records: 3  
}

The record data might be returned as two chunks, where the first chunk is

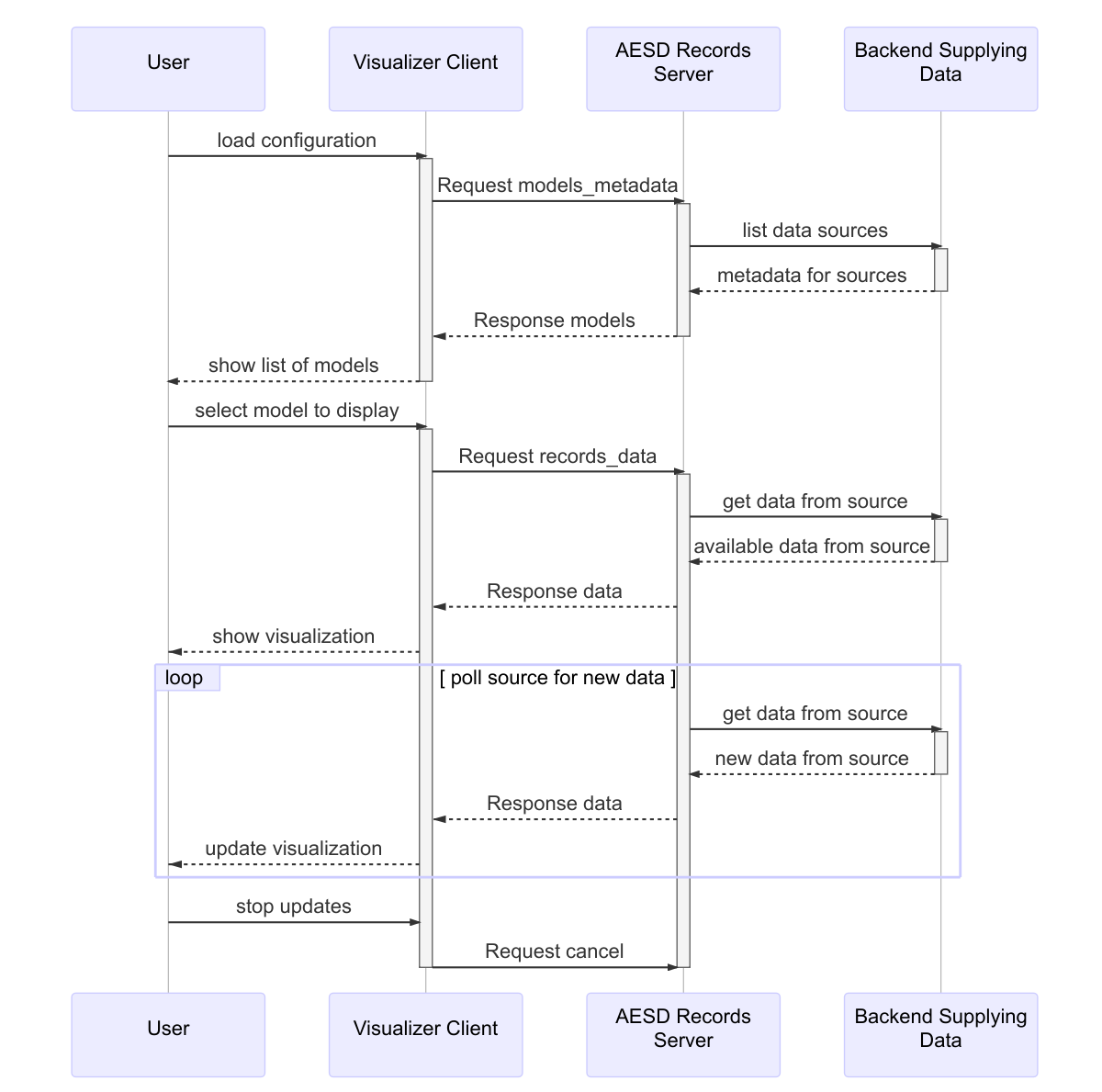
version: 4  
id: 2  
chunk\_id: 1  
next\_chunk\_id: 2  
data {  
 list {  
 records {  
 record\_id: 10  
 variables {  
 var\_id: 0  
 value: 10.5  
 }  
 variables {  
 var\_id: 1  
 value: -5  
 }  
 variables {  
 var\_id: 2  
 value: "first"  
 }  
 }  
 records {  
 record\_id: 20  
 variables {  
 var\_id: 0  
 value: 99.2  
 }  
 variables {  
 var\_id: 1  
 value: 108  
 }  
 variables {  
 var\_id: 2  
 value: "second"  
 }  
 }  
 }  
}

and the last chunk is:

version: 4  
id: 2  
chunk\_id: 2  
next\_chunk\_id: 0  
data {  
 list {  
 records {  
 record\_id: 30  
 variables {  
 var\_id: 0  
 value: -15.7  
 }  
 variables {  
 var\_id: 1  
 value: 30  
 }  
 variables {  
 var\_id: 2  
 value: "third"  
 }  
 }  
 }  
}

## Dynamic Data

As shown in the following figure retrieving data from a dynamic source proceeds quite similarly to retrieving data from a static source. The only essential difference is that the server repeatedly sends additional responses containing new data, until a request to cancel is sent:



Visualizing data from a dynamic source using the AESD Records API.

When requesting dynamic data, it is advisable to set the subscribe flag in the request for data:

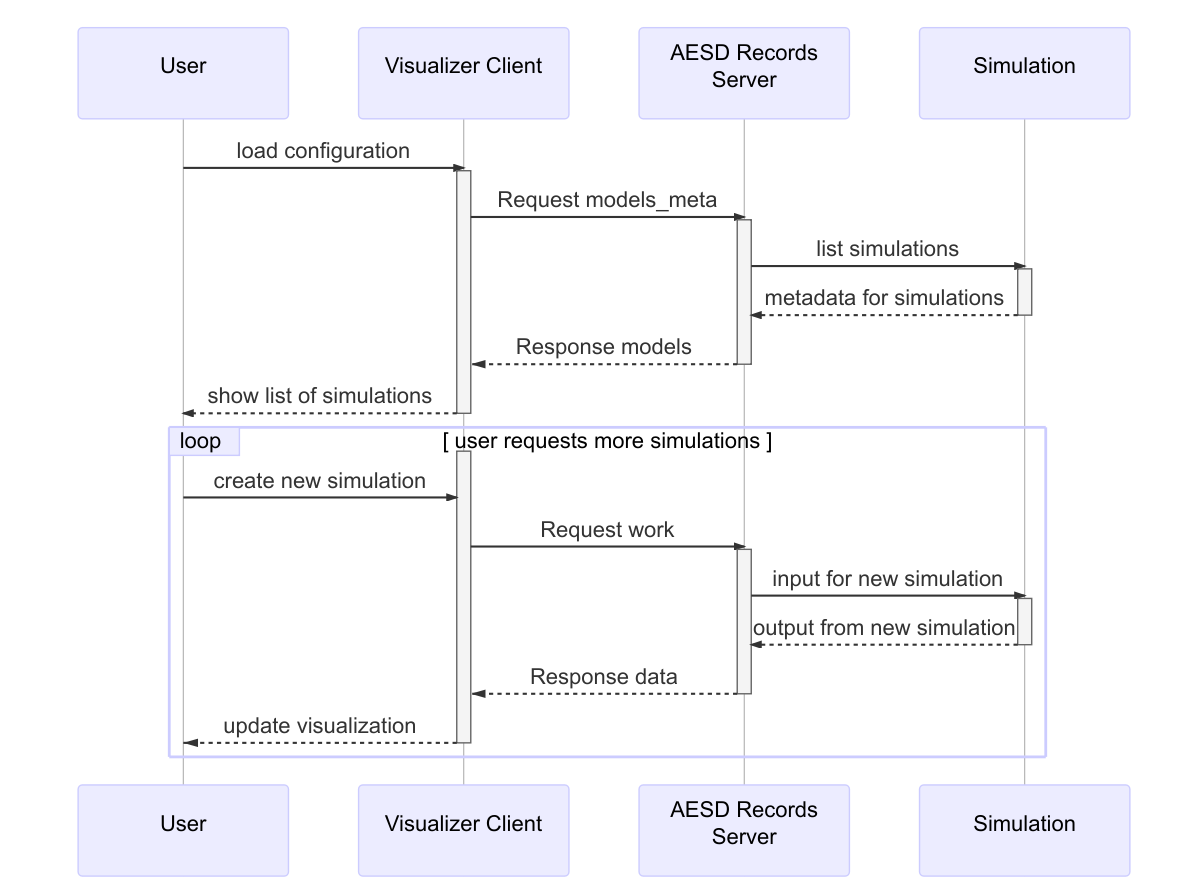
version: 4  
id: 2  
subscribe: true  
records\_data {  
 model\_id: "example-model-2"  
}

The [RequestCancel](#EsdaRecords.RequestCancel) message is the cancel field [Request](#EsdaRecords.Request) and must include the id of the request to be cancelled:

version: 4  
cancel {  
 id: 2  
}

## Simulations

The model Example Simulation #3 in the Static Data use case is a simulation model, as evidenced by the presence of the inputs field in its metadata. The following figure shows a typical interaction with a simulation-based model via the Records API.



Steering and visualizing simulation results using the AESD Records API.

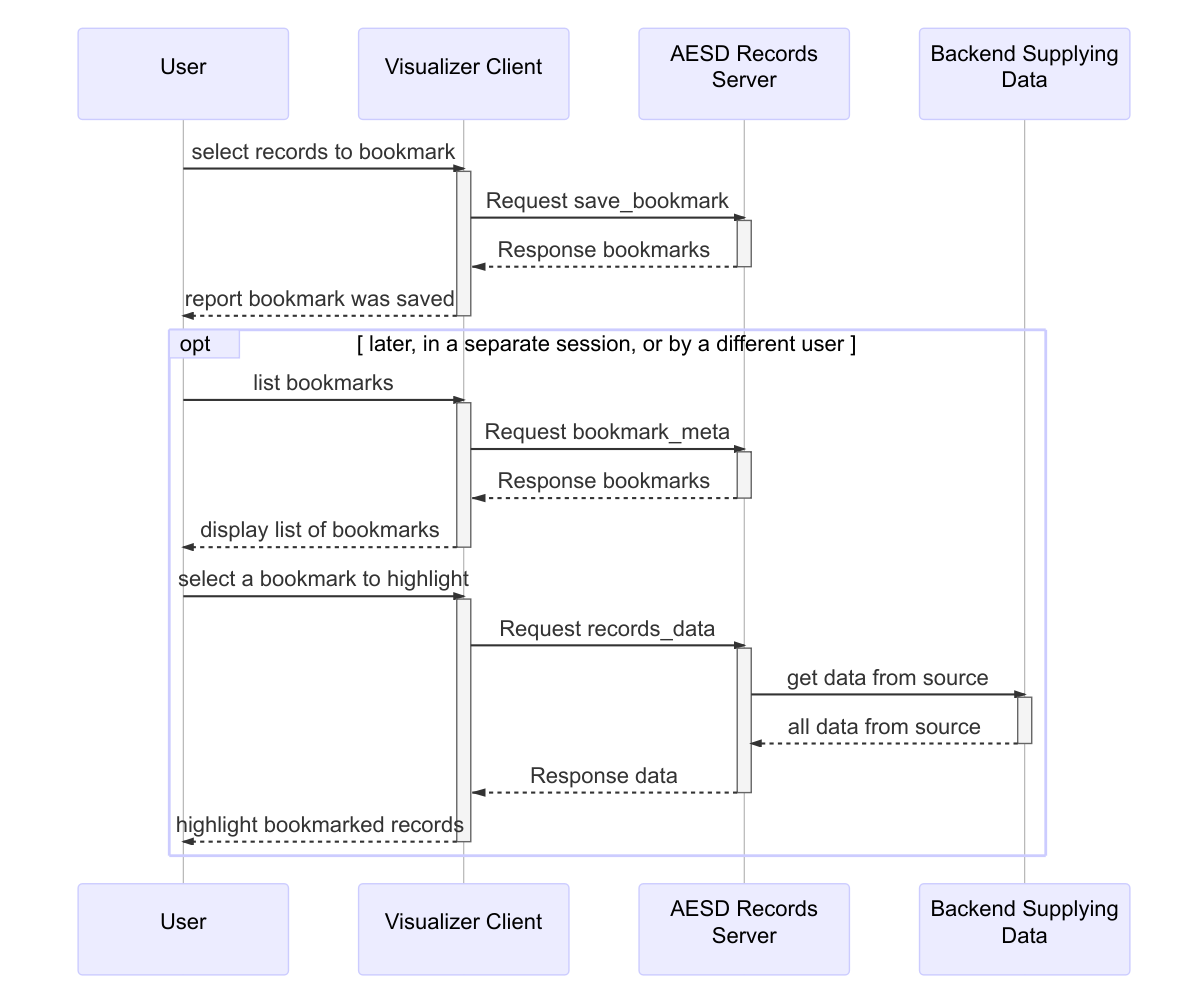
The [RequestWork](#EsdaRecords.RequestWork) message, which is contained in the work field of a [Request](#EsdaRecords.Request), specifies the input for a simulation to be run:

version: 4  
id: 3  
work {  
 model\_id: "example-simulation-3"  
 inputs {  
 var\_id: 0  
 value: 50  
 }  
}

The response to this message will be data for the result of the simulation.

## Bookmarks

Once data from a model is loaded, it may be bookmarked. One simply supplies a description of the data to be bookmarked. Bookmarks can be listed and loaded, as shown in the following figure.



Creating and retrieving a bookmark and its associated data.

To create a bookmark for a specific list of records, simply supply their record identifiers as part of a [BookmarkMeta](#EsdaRecords.BoomarkMeta) message in the save\_bookmark field of [Request](#EsdaRecords.Request):

version: 4  
id: 4  
save\_bookmark {  
 model\_id: "example-model-1"  
 new\_bookmark {  
 bookmark\_name: "Sample Bookmark"  
 set {  
 record\_ids: 10  
 record\_ids: 30  
 }  
 }  
}

The response will be the same bookmark, but with the bookmark\_id field added:

version: 4  
id: 4  
bookmarks {  
 bookmark\_metas {  
 bookmark\_id: "bookmark-1"  
 bookmark\_name: "Sample Bookmark"  
 set {  
 record\_ids: 10  
 record\_ids: 30  
 }  
 }  
}

The user or another user can retrieve the records corresponding to the bookmark:

version: 4  
id: 5  
records\_data {  
 model\_id: "example-model-1"  
 bookmark\_id: "bookmark-1"  
}

This will return precisely the bookmarked records:

version: 4  
id: 5  
data {  
 list {  
 records {  
 record\_id: 10  
 variables {  
 var\_id: 0  
 value: 10.5  
 }  
 variables {  
 var\_id: 1  
 value: -5  
 }  
 variables {  
 var\_id: 2  
 value: "first"  
 }  
 }  
 records {  
 record\_id: 30  
 variables {  
 var\_id: 0  
 value: -15.7  
 }  
 variables {  
 var\_id: 1  
 value: 30  
 }  
 variables {  
 var\_id: 2  
 value: "third"  
 }  
 }  
 }  
}

## Filtering

Filtering records can be used to select particular records for retrieval, via the [RequestRecordsData](#EsdaRecords.RequestRecordsData) message, or in defining bookmarks, via the [BookmarkMeta](#EsdaRecords.BookmarkMeta) message. The filtering of records is accomplished through expressions, [FilterExpression](#EsdaRecords.FilterExpression), combining values for variables, [DomainMeta](#EsdaRecords.DomainMeta), and the set operators not, union, and intersection, encoded in the messages [FilterNot](#EsdaRecords.FilterNot), [FilterUnion](#EsdaRecords.FilterUnion), and [FitlerIntersection](#EsdaRecords.FilterExpression), respectively. For example, the expression would be expressed as the following [FilterExpression](#EsdaRecords.FilterExpression)

filter\_domain {  
 interval {  
 var\_id: 0  
 last\_value: 20  
 }  
}

provided that has var\_id = 0. The expression would be expressed as

filter\_union {  
 filter\_expressions {  
 filter\_domain {  
 var\_id: 0  
 first\_value: 10  
 last\_value: 20  
 }  
 filter\_not {  
 filter\_expression {  
 filter\_domain {  
 var\_id: 1  
 set {  
 elements: 4  
 elements: 7  
 }  
   
 }  
 }  
 }  
}

provided that has var\_id = 0 and has var\_id = 1.

# Records API, Version 4

The AESD Records API consists of Google Protobuf 3 (Google Developers 2017b) messages used for requesting and providing data and metadata for record-oriented information. This section contains the complete specification for version 4 of the Records API. Clients send Request messages and servers send Response messages, typically transported via WebSockets (Internet Engineering Task Force 2017).

## Message Groups

The message types in the Records API are organized into thematic groups below.

### Requests and Responses

Request messages are sent from client to server and Response messages are sent from server to client. Request messages contain a specific type of request and response messages contain a corresponding specific type of response.

* [Request](#AesdRecords.Request)
* [RequestModelsMeta](#AesdRecords.RequestModelsMeta)
* [RequestRecordsData](#AesdRecords.RequestRecordsData)
* [RequestWork](#AesdRecords.RequestWork)
* [RequestBoomarkMeta](#AesdRecords.RequestBoomarkMeta)
* [RequestSaveBookmark](#AesdRecords.RequestSaveBookmark)
* [RequestCancel](#AesdRecords.RequestCancel)
* [Response](#AesdRecords.Response)

### Metadata

Metadata messages describe data sources (“models”) and variables.

* [ModelMeta](#AesdRecords.ModelMeta)
* [ModelMetaList](#AesdRecords.ModelMetaList)
* [DomainMeta](#AesdRecords.DomainMeta)
* [VarMeta](#AesdRecords.VarMeta)
* [VariableType](#AesdRecords.VariableType)
* [VarSet](#AesdRecords.VarSet)
* [VarInterval](#AesdRecords.VarInterval)

### Data Records

Data is represented as either lists of records or tables of them.

* [Record](#AesdRecords.Record)
* [VarValue](#AesdRecords.VarValue)
* [Value](#AesdRecords.Value)
* [RecordData](#AesdRecords.RecordData)
* [RecordList](#AesdRecords.RecordList)
* [RecordTable](#AesdRecords.RecordTable)

### Filtering

Records can be filtered by logical operations on conditions on values of variables in the records.

* [FilterExpression](#AesdRecords.FilterExpression)
* [FilterNot](#AesdRecords.FilterNot)
* [FilterIntersection](#AesdRecords.FilterIntersection)
* [FilterUnion](#AesdRecords.FilterUnion)
* [DomainMeta](#AesdRecords.DomainMeta)

### Bookmarks

Bookmarks record particular sets or records or conditions on record data.

* [BookmarkMeta](#AesdRecords.BookmarkMeta)
* [BookmarkMetaList](#AesdRecords.BookmarkMetaList)
* [BookmarkIntervalContent](#AesdRecords.BookmarkIntervalContent)
* [BookmarkSetContent](#AesdRecords.BookmarkSetContent)

### Miscellaneous

The following messages wrap data types for the content of records.

* [DoubleList](#AesdRecords.DoubleList)
* [IntegerList](#AesdRecords.IntegerList)
* [StringList](#AesdRecords.StringList)
* [OptionalInt32](#AesdRecords.OptionalInt32)
* [OptionalUInt32](#AesdRecords.OptionalUInt32)
* [OptionalString](#AesdRecords.OptionalString)

## General conventions

All fields are technically optional in ProtoBuf 3, but some fields may be required in each message type in order for the message to be semantically valid. In the following specifications for the messages, fields are annotated as *semantically required* or *semantically optional*. Also, the specification notes when field in the [protobuf oneof construct](https://developers.google.com/protocol-buffers/docs/proto3#oneof) are required or mutually exclusive.

Furthermore, one cannot determine whether an optional value has been set or not if it is just a value, as opposed to a message. That is not true for fields that are messages, where the absence of the field truly indicates that the value is absent, not just a default or unset value. The message OptionalString, for example, is used in this API to indicate whether a character string value is truly present. Thus [RequestModelsMeta](#AesdRecords.RequestModelsMeta) has a model\_id field that indicates whether the request is for all models, when the field has not been set, or for a specific one, when the field has been set.

Throughout this specification, the following types are used for identifiers: \* var\_id is [int32](#int32) \* model\_id is [string](#string) \* record\_id is [int64](#int64)

This specification conforms to [Protocol Buffers version 3](https://developers.google.com/protocol-buffers/docs/proto3).

## Messages

### BookmarkIntervalContent

A range of [record identifiers](#AesdRecords.Record) can specify the content of a [bookmark](#AesdRecords.BookmarkMeta). Bookmark interval content provides a convenient means to bookmark a contiguous selection of records in a [model](#AesdRecords.ModelMeta).

Both fields in this message are optional:

* If neither field is present, then the bookmark interval designates all records in the model.
* If only first\_recordis present, then the bookmark interval designates all records starting from that record identifier.
* If only last\_record is present, then the bookmark interval designates all records ending at that record identifier. For a dynamic model, such a bookmark interval includes all “future” records.
* If both fields are present, then the bookmark interval designates all records between the two identifiers, inclusive.

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| first\_record | [int64](#int64) | optional | [semantically optional] The identifier for the first record in the interval. |
| last\_record | [int64](#int64) | optional | [semantically optional] The identifier for the last record in the interval. |

### BookmarkMeta

A bookmark is metadata defining a subset of records in a [model](#AesdRecords.ModelMeta).

There are three alternatives to specifying a bookmark:

1. [Interval content](#AesdRecords.BookmarkIntervalContent) specifies a range of records in the bookmark.
2. [Set content](#AesdRecords.BookmarkSetContent) specifies a list of records in the bookmark.
3. A [filter expression](#AesdRecords.FilterExpression) defines a set of logical conditions for determining whether a record is in the bookmark.

*Exactly one of interval, set, or filter must be specified in this message.*

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| bookmark\_id | [string](#string) | optional | [semantically optional] When creating a new bookmark, this field must be empty: the server will create a unique identifier for the bookmark. This identifier uniquely identifies the bookmark *on the particular server*. |
| bookmark\_name | [string](#string) | optional | [semantically required] A name for the bookmark, useful for displaying the bookmark to users. This need not be unique, although it is recommended to be so. |
| interval | [BookmarkIntervalContent](#AesdRecords.BookmarkIntervalContent) | optional | The range of records in the bookmark. |
| set | [BookmarkSetContent](#AesdRecords.BookmarkSetContent) | optional | The list of records in the bookmark. |
| filter | [FilterExpression](#AesdRecords.FilterExpression) | optional | Logical conditions for defining which records are in the bookmark. |

### BookmarkMetaList

Bookmarks may be grouped into lists (sets).

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| bookmark\_metas | [BookmarkMeta](#AesdRecords.BookmarkMeta) | repeated | [semantically optional] The bookmarks in the list. |

### BookmarkSetContent

A list (set) of [record identifiers](#AesdRecords.Record) can specify the contents of a [bookmark](#AesdRecords.BookmarkMeta). Bookmark set content provides a convenient means to bookmark a specific selection of non-continuous records in a [model](#AesdRecords.ModelMeta).

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| record\_ids | [int64](#int64) | repeated | [semantically optional] The list of record identifiers in the set. |

### DomainMeta

The domain (set of valid values) for a variable.

There are two alternatives to specifying a domain:

1. [An interval](#AesdRecords.VarInterval) specifies a range of values in the domain.
2. [A set](#AesdRecords.VarSet) specifies a list of values in the domain.

*Exactly one of interval or set must be specified in the message.*

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| var\_id | [int32](#int32) | optional | [semantically required] |
| interval | [VarInterval](#AesdRecords.VarInterval) | optional | The interval of values in the domain. |
| set | [VarSet](#AesdRecords.VarSet) | optional | The list of values in the domain. |

### DoubleList

A list of real numbers.

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| values | [double](#double) | repeated | [semantically required] The real numbers. |

### FilterExpression

A filtering expression is a composition of logical conditions on a [record](#AesdRecords.Record). It can be used to filter records. There are four alternatives to specifying a filter expression:

1. The [logical negation](#AesdRecords.FilterNot) of another filtering expression.
2. The [set union](#AesdRecords.FilterUnion) of multiple filtering expressions.
3. The [set intersection](#AesdRecords.FilterIntersection) of multiple filtering expressions.
4. [Particular values](#AesdRecords.DomainMeta) of variables in a record.

*Exactly one of filter\_not, filter\_union, filter\_intersection, or filter\_domain must be specified in this message.*

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| filter\_not | [FilterNot](#AesdRecords.FilterNot) | optional | Logical negation of an expression. |
| filter\_union | [FilterUnion](#AesdRecords.FilterUnion) | optional | Set union of expressions. |
| filter\_intersection | [FilterIntersection](#AesdRecords.FilterIntersection) | optional | Set intersection of expressions. |
| filter\_domain | [DomainMeta](#AesdRecords.DomainMeta) | optional | Particular values of variables. |

### FilterIntersection

Set intersection of filtering expressions. A record satisfies this expression if it satisfies all of filter\_expressions.

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| filter\_expressions | [FilterExpression](#AesdRecords.FilterExpression) | repeated | [semantically required] The expressions to be intersected. |

### FilterNot

Logically negate a filtering expression. A record satisfies this expression if it does not satisfy filter\_expression.

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| filter\_expression | [FilterExpression](#AesdRecords.FilterExpression) | optional | [semantically required] The expression to be negated. |

### FilterUnion

Set union of filtering expressions. A record satisfies this expression if it satisfies any of filter\_expressions.

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| filter\_expressions | [FilterExpression](#AesdRecords.FilterExpression) | repeated | [semantically required] The expressions to be unioned. |

### IntegerList

A list of integers.

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| values | [sint64](#sint64) | repeated | [semantically required] The integers. |

### ModelMeta

Metadata for a model.

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| model\_id | [string](#string) | optional | [semantically required] The unique identifier for the model *on the particular server*. |
| model\_name | [string](#string) | optional | [semantically required] A name for the model, useful for display the model to users. This need not be unique, although it is recommended to be so. |
| model\_uri | [string](#string) | optional | [semantically required] The unique URI for the model. Additional metadata may be obtained by dereferencing that URI. |
| variables | [VarMeta](#AesdRecords.VarMeta) | repeated | [semantically required] Metadata for the variables. |
| inputs | [DomainMeta](#AesdRecords.DomainMeta) | repeated | [semantically optional] Metadata for input values to the model, if any. |

### ModelMetaList

A list of metadata for models.

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| models | [ModelMeta](#AesdRecords.ModelMeta) | repeated | [semantically optional] The metadata for the models. |

### OptionalInt32

Wrapper for an optional signed integer.

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| value | [int32](#int32) | optional | [semantically required] The signed integer value. |

### OptionalString

Wrapper for an optional string.

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| value | [string](#string) | optional | [semantically required] The character string value. |

### OptionalUInt32

Wrapper for an optional unsigned integer.

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| value | [uint32](#uint32) | optional | [semantically required] The unsigned integer value. |

### Record

A record is a list of variables and their associated values.

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| record\_id | [int64](#int64) | optional | [semantically required] A unique identifier for the record. |
| variables | [VarValue](#AesdRecords.VarValue) | repeated | [semantically optional] The values for variables in the record. |

### RecordData

A collection or records.

There are two alternatives to specifying record data:

1. [A list](#AesdRecords.RecordList) specifies a heterogeneously typed list.
2. [A table](#AesdRecords.RecordTable) specifies a homogeneously typed table.

*Exactly one of list or table must be present in the message.*

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| list | [RecordList](#AesdRecords.RecordList) | optional | A heterogeneously typed list of records. |
| table | [RecordTable](#AesdRecords.RecordTable) | optional | A homogeneously typed table of records. |

### RecordList

A list of records. The list is heterogeneous in the sense that each variable may have a different type.

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| records | [Record](#AesdRecords.Record) | repeated | [semantically optional] The list of records. |

### RecordTable

A homogeneously typed table of records, where each variable has each type, with a row for each record and a column for each variable.

This message represents the following table:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Record Identifier | var\_id[0] | var\_id[1] | . . . | var\_id[N] |
| rec\_id[0] | list[0][0] | list[0][1] | . . . | list[0][N] |
| rec\_id[1] | list[1][0] | list[1][1] | . . . | list[1][N] |
| . . . | . . . | . . . | . . . | . . . |
| rec\_id[M] | list[M][0] | list[M][1] | . . . | list[M][N] |

The underlying list is a **single** array, addressable using the following [row-major index formula](https://en.wikipedia.org/wiki/Row-_and_column-major_order) list[row][var] = array[var + NY \* row] where NX = length of rec\_ids and NY = length of var\_ids.

*Exacly one of reals, integers, or strings must be specified in the message.*

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| var\_ids | [int32](#int32) | repeated | [semantically required] The identifiers of the variables (columns) in the table. |
| rec\_ids | [int64](#int64) | repeated | [semantically required] The identifiers of the records (rows) in the table. |
| reals | [DoubleList](#AesdRecords.DoubleList) | optional | The real numbers comprising the values of the variables, in [row-major order](https://en.wikipedia.org/wiki/Row-_and_column-major_order). |
| integers | [IntegerList](#AesdRecords.IntegerList) | optional | The integers comprising the values of the variables, in [row-major order](https://en.wikipedia.org/wiki/Row-_and_column-major_order). |
| strings | [StringList](#AesdRecords.StringList) | optional | The character strings comprising the values of the variables, in [row-major order](https://en.wikipedia.org/wiki/Row-_and_column-major_order). |

### Request

A request. There are six types of requests:

|  |  |
| --- | --- |
| Request | Response |
| Metadata for model(s) | [ModelMetaList](#AesdRecords.ModelMetaList) |
| Data records | [RecordData](#AesdRecords.RecordData) |
| Metadata for bookmark(s) | [BookmarkMetaList](#AesdRecords.BookmarkMetaList) |
| Saving a bookmark | [BookmarkMetaList](#AesdRecords.BookmarkMetaList) |
| Canceling a previous request | n/a |
| New work, such as a simulation | [RecordData](#AesdRecords.RecordData) |

\*Exactly one of models\_metadata, records\_data, bookmark\_meta, save\_bookmark, cancel, or work must be specified in the message.

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| version | [uint32](#uint32) | optional | [semantically required] The version number for the API. *This must be the number* ***four****.* |
| id | [OptionalUInt32](#AesdRecords.OptionalUInt32) | optional | [semantically optional, but recommended] An identifier which will be used to tag responses, so that responses can be correlated with requests. |
| subscribe | [bool](#bool) | optional | [semantically optional] Whether to continue receiving responses indefinitely, as new records become available. This is useful, for example, when a sensor is reporting measurements periodically or when simulations are reporting a series or results. Use [RequestCancel](#AesdRecords.RequestCancel) to end the subscription. |
| models\_metadata | [RequestModelsMeta](#AesdRecords.RequestModelsMeta) | optional | Request metadata for model(s). |
| records\_data | [RequestRecordsData](#AesdRecords.RequestRecordsData) | optional | Request data records. |
| bookmark\_meta | [RequestBookmarkMeta](#AesdRecords.RequestBookmarkMeta) | optional | Request metadata for bookmark(s). |
| save\_bookmark | [RequestSaveBookmark](#AesdRecords.RequestSaveBookmark) | optional | Request save a new bookmark or update an existing one. |
| cancel | [RequestCancel](#AesdRecords.RequestCancel) | optional | Request cancel a previous request). |
| work | [RequestWork](#AesdRecords.RequestWork) | optional | Request request work (e.g., simulation results). |

### RequestBookmarkMeta

A request for one or more bookmarks for a [model](#AesdRecords.ModelMeta).

The response to this request is [BookmarkMetaList](#AesdRecords.MetaList)

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| model\_id | [string](#string) | optional | [semantically required] Which model for which to list bookmarks. |
| bookmark\_id | [OptionalString](#AesdRecords.OptionalString) | optional | [semantically optional] If empty, list all bookmarks for the model. Otherwise, list just the bookmark metadata for this specific bookmark identifier. |

### RequestCancel

Cancel a previous request.

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| id | [OptionalUInt32](#AesdRecords.OptionalUInt32) | optional | [semantically required] Which request to cancel. |

### RequestModelsMeta

A request for metadata about model(s).

The response to this request is [ModelMetaList](#AesdRecords.ModelMetaList).

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| model\_id | [OptionalString](#AesdRecords.OptionalString) | optional | [semantically optional] If absent, the request is for metadata for all models. Otherwise the request is for the specifically identified model. |

### RequestRecordsData

Request record data for a model.

There are three alternatives to requesting record data.

1. Request all records.
2. Request records in [a bookmark](#AesdRecords.BookmarkMeta).
3. [Filter](#AesdRecords.FilterExpression) records according to a criterion.

The response to this request is [RecordData](#AesdRecords.RecordData).

*No more than on of bookmark\_id or expression may be present in the message.*

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| model\_id | [string](#string) | optional | [semantically required] The identifier for the model. |
| max\_records | [uint64](#uint64) | optional | [semantically optional] If specified, this is the maximum number of records to return. Otherwise all records are returned, although they may be returned as multiple responses, each with a chunk of records. |
| var\_ids | [int32](#int32) | repeated | [semantically optional] Which variables to include in the response. If this is not specified, all variables will be included. |
| bookmark\_id | [string](#string) | optional | [semantically optional] Only respond with records in a specified bookmark. |
| expression | [FilterExpression](#AesdRecords.FilterExpression) | optional | [semantically optional] Only respond with records matching a specified criterion. |

### RequestSaveBookmark

A request to create or update a bookmark.

The response to this request is [BookmarkMetaList](#AesdRecords.BookmarkMetaList).

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| model\_id | [string](#string) | optional | [semantically required] Which model for which to save the bookmark. |
| new\_bookmark | [BookmarkMeta](#AesdRecords.BookmarkMeta) | optional | [semantically optional] If empty, create a new bookmark. (In which case, leave the bookmark\_id empty, so that the server will create a unique identifier for the new bookmark.) Otherwise, update an existing bookmark. |

### RequestWork

Request that the server compute new records based on input values.

The response to this request is [RecordData](#AesdRecords.RecordData).

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| model\_id | [string](#string) | optional | [semantically required] The identifier for the model. |
| inputs | [VarValue](#AesdRecords.VarValue) | repeated | [semantically optional] Which input variables to set to which values. |

### Response

A response to a request.

Note that a server may send multiple responses to a single request, expressed as a linked list of chunks. It is strongly recommended that servers chunk by record\_id so that each record is kept intact. A chunk may be empty.

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| version | [uint32](#uint32) | optional | [semantically required] The version number for the API. *This must be the number* ***four****.* |
| id | [OptionalUInt32](#AesdRecords.OptionalUInt32) | optional | [semantically optional] A response without an identifier is a notification. Otherwise, the response identifier matches the response identifier for the original request. |
| chunk\_id | [int32](#int32) | optional | [semantically optional, but recommended] The identifier for this chunk. It is recommended that chunks are number sequentially starting from one. |
| next\_chunk\_id | [int32](#int32) | optional | [semantically optional] The identifier of the next chunk, or zero if this is the last chunk. |
| error | [string](#string) | optional | An error message. |
| models | [ModelMetaList](#AesdRecords.ModelMetaList) | optional | A list of model metadata. |
| data | [RecordData](#AesdRecords.RecordData) | optional | A list of record data. |
| bookmarks | [BookmarkMetaList](#AesdRecords.BookmarkMetaList) | optional | A list of bookmark metadata. |

### StringList

A list of character strings.

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| values | [string](#string) | repeated | [semantically required] The character strings. |

### Value

Value that may be a real number, an integer, or a character string

*Exactly one of real\_value, integer\_value, or string\_value must be specified in this message.*

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| real\_value | [double](#double) | optional | The real number. |
| integer\_value | [int64](#int64) | optional | The integer. |
| string\_value | [string](#string) | optional | The character string. |

### VarInterval

A range of values of a [variable](#AesdRecords.VarMeta).

Both fields in this message are optional:

* If neither field is present, then the interval designates all values in the domain.
* If only first\_valueis present, then the interval designates all values starting from that value.
* If only last\_value is present, then the bookmark interval designates all values ending at that value.
* If both fields are present, then the interval designates all values between the two values, inclusive.

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| first\_value | [Value](#AesdRecords.Value) | optional | [semantically optional] The first value in the interval. |
| last\_value | [Value](#AesdRecords.Value) | optional | [semantically optional] The last value in the interval. |

### VarMeta

Metadata for a variable.

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| var\_id | [int32](#int32) | optional | [semantically required] A integer identifying the variable. |
| var\_name | [string](#string) | optional | [semantically required] The name of the variable. |
| units | [string](#string) | optional | [semantically optional] The name of the unit of measure for values of the variable. |
| si | [sint32](#sint32) | repeated | [semantically optional] The unit of measure expressed as a list of the exponents for the eigth fundamental SI quantities [meter, kilogram, second, ampere, kelvin, mole, calenda, radian]. For example, the unit of acceleration would be express as [1, 0, -2, 0, 0, 0, 0, 0] because meters has an exponent of positive one and seconds has an exponent of negative two. |
| scale | [double](#double) | optional | [semantically optional] An overall scale relative to the fundamental SI scale of the unit of measure. For instance, kilometers would have a scale 1000 because the fundamental unit of distance is meters. |
| type | [VariableType](#AesdRecords.VariableType) | optional | [semantically optional] The data type for values of the variable. The default type is real number. |

### VarSet

A set of values for a variable.

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| elements | [Value](#AesdRecords.Value) | repeated | [semantically optional] The list of values in the set. |

### VarValue

The value of a variable.

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Type | Label | Description |
| var\_id | [int32](#int32) | optional | [semantically required] The identifier for the variable. |
| value | [Value](#AesdRecords.Value) | optional | [semantically required] The value of the variable. |

### VariableType

The data type for a value.

|  |  |  |
| --- | --- | --- |
| Name | Number | Description |
| REAL | 0 | A real number. |
| INTEGER | 1 | An integer. |
| STRING | 2 | A character string. |

## Scalar Value Types

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| .proto Type | Notes | C++ Type | Java Type | Python Type |
| double |  | double | double | float |
| float |  | float | float | float |
| int32 | Uses variable-length encoding. Inefficient for encoding negative numbers – if your field is likely to have negative values, use sint32 instead. | int32 | int | int |
| int64 | Uses variable-length encoding. Inefficient for encoding negative numbers – if your field is likely to have negative values, use sint64 instead. | int64 | long | int/long |
| uint32 | Uses variable-length encoding. | uint32 | int | int/long |
| uint64 | Uses variable-length encoding. | uint64 | long | int/long |
| sint32 | Uses variable-length encoding. Signed int value. These more efficiently encode negative numbers than regular int32s. | int32 | int | int |
| sint64 | Uses variable-length encoding. Signed int value. These more efficiently encode negative numbers than regular int64s. | int64 | long | int/long |
| fixed32 | Always four bytes. More efficient than uint32 if values are often greater than 2^28. | uint32 | int | int |
| fixed64 | Always eight bytes. More efficient than uint64 if values are often greater than 2^56. | uint64 | long | int/long |
| sfixed32 | Always four bytes. | int32 | int | int |
| sfixed64 | Always eight bytes. | int64 | long | int/long |
| bool |  | bool | boolean | boolean |
| string | A string must always contain UTF-8 encoded or 7-bit ASCII text. | string | String | str/unicode |
| bytes | May contain any arbitrary sequence of bytes. | string | ByteString | str |

# Appendices

## Protocol Buffers for Records API Version 4

syntax = "proto3";  
package AesdRecords;  
  
option optimize\_for = LITE\_RUNTIME;  
  
message OptionalInt32 {  
 int32 value = 1; /// [semantically required]  
}  
  
message OptionalUInt32 {  
 uint32 value = 1; /// [semantically required]  
}  
  
message OptionalString {  
 string value = 1; /// [semantically required]  
}  
  
message Value {  
 oneof value /// [semantically required]  
 {  
 double real\_value = 1;   
 int64 integer\_value = 2;   
 string string\_value = 3;   
 }  
}  
  
message DoubleList {  
 repeated double values = 1; /// [semantically required]  
}  
  
message IntegerList {  
 repeated sint64 values = 1; /// [semantically required]  
}  
  
message StringList {  
 repeated string values = 1; /// [semantically required]  
}  
  
message BookmarkIntervalContent {  
 int64 first\_record = 1; /// [semantically optional]  
 int64 last\_record = 2; /// [semantically optional]  
}  
  
message BookmarkSetContent {  
 repeated int64 record\_ids = 1; /// [semantically optional]  
}  
  
message BookmarkMeta {  
 string bookmark\_id = 1; /// [semantically optional]  
 string bookmark\_name = 2; /// [semantically required]  
 oneof content /// [semantically required]  
 {  
 BookmarkIntervalContent interval = 3;   
 BookmarkSetContent set = 4;   
 FilterExpression filter = 5;   
 }  
}  
  
message BookmarkMetaList {  
 repeated BookmarkMeta bookmark\_metas = 1; /// [semantically optional]  
}  
  
message RequestBookmarkMeta {  
 string model\_id = 1; /// [semantically required]  
 OptionalString bookmark\_id = 2; /// [semantically optional]  
}  
  
message RequestSaveBookmark {  
 string model\_id = 1; /// [semantically required]  
 BookmarkMeta new\_bookmark = 2; /// [semantically optional]  
}  
  
message FilterExpression {  
 oneof expression /// [semantically required]  
 {  
 FilterNot filter\_not = 1;   
 FilterUnion filter\_union = 2;   
 FilterIntersection filter\_intersection = 3;   
 DomainMeta filter\_domain = 4;   
 }  
}  
  
message FilterNot {  
 FilterExpression filter\_expression = 1; /// [semantically required]  
}  
  
message FilterUnion {  
 repeated FilterExpression filter\_expressions = 1; /// [semantically required]  
}  
  
message FilterIntersection {  
 repeated FilterExpression filter\_expressions = 1; /// [semantically required]  
}  
  
enum VariableType  
{  
 REAL = 0;   
 INTEGER = 1;   
 STRING = 2;   
}  
  
message VarMeta {  
 int32 var\_id = 1; /// [semantically required]  
 string var\_name = 2; /// [semantically required]  
 string units = 3; /// [semantically optional]  
 repeated sint32 si = 4; /// [semantically optional]  
 double scale = 5; /// [semantically optional]  
 VariableType type = 6; /// [semantically optional]  
}  
  
message ModelMeta {  
 string model\_id = 1; /// [semantically required]  
 string model\_name = 2; /// [semantically required]  
 string model\_uri = 3; /// [semantically required]  
 repeated VarMeta variables = 4; /// [semantically required]  
 repeated DomainMeta inputs = 5; /// [semantically optional]  
}  
  
message ModelMetaList {  
 repeated ModelMeta models = 1; /// [semantically optional]  
}  
  
message RequestModelsMeta {  
 OptionalString model\_id = 1; /// [semantically optional]  
}  
  
message VarInterval {  
 Value first\_value = 1; /// [semantically optional]  
 Value last\_value = 2; /// [semantically optional]  
}  
  
message VarSet {  
 repeated Value elements = 1; /// [semantically optional]  
}  
  
message DomainMeta {  
 int32 var\_id = 1; /// [semantically required]  
 oneof domain /// [semantically required]  
 {  
 VarInterval interval = 2;   
 VarSet set = 3;   
 }  
}  
  
message RequestWork {  
 string model\_id = 1; /// [semantically required]  
 repeated VarValue inputs = 2; /// [semantically optional]  
}  
  
message VarValue {  
 int32 var\_id = 1; /// [semantically required]  
 Value value = 2; /// [semantically required]  
}  
  
message Record {  
 int64 record\_id = 1; /// [semantically required]  
 repeated VarValue variables = 2; /// [semantically optional]  
}  
  
message RecordList {  
 repeated Record records = 1; /// [semantically optional]  
}  
  
message RecordTable {  
 repeated int32 var\_ids = 1; /// [semantically required]  
 repeated int64 rec\_ids = 2; /// [semantically required]  
 oneof list /// [semantically required]  
 {  
 DoubleList reals = 3;   
 IntegerList integers = 4;   
 StringList strings = 5;   
 }  
}  
  
message RecordData {  
 oneof style /// [semantically required]  
 {  
 RecordList list = 1;   
 RecordTable table = 2;   
 }  
}  
  
message RequestRecordsData {  
 string model\_id = 1; /// [semantically required]  
 uint64 max\_records = 2; /// [semantically optional]  
 repeated int32 var\_ids = 3; /// [semantically optional]  
 oneof filter /// [semantically optional]  
 {  
 string bookmark\_id = 4; /// [semantically optional]  
 FilterExpression expression = 5; /// [semantically optional]  
 }  
}  
  
message Response {  
 uint32 version = 1; /// [semantically required]  
 OptionalUInt32 id = 2; /// [semantically optional]  
 int32 chunk\_id = 3; /// [semantically optional, but recommended]  
 int32 next\_chunk\_id = 4; /// [semantically optional]  
 oneof type /// [semantically optional]  
 {  
 string error = 5;   
 ModelMetaList models = 6;   
 RecordData data = 7;   
 BookmarkMetaList bookmarks = 8;   
 }  
}  
  
message RequestCancel {  
 OptionalUInt32 id = 1; /// [semantically required]  
}  
  
message Request {  
 uint32 version = 1; /// [semantically required]  
 OptionalUInt32 id = 2; /// [semantically optional, but recommended]  
 bool subscribe = 3; /// [semantically optional]  
 oneof type /// [semantically required]  
 {  
 RequestModelsMeta models\_metadata = 4;   
 RequestRecordsData records\_data = 5;   
 RequestBookmarkMeta bookmark\_meta = 6;   
 RequestSaveBookmark save\_bookmark = 7;   
 RequestCancel cancel = 8;   
 RequestWork work = 9;   
 }  
}

# References

Fowler, Martin. 2017. “UML Distilled.” Accessed April 11. <http://my.safaribooksonline.com/book/software-engineering-and-development/uml/0321193687/sequence-diagrams/ch04>.

Google Developers. 2017a. “Protocol Buffers - Google’s Data Interchange Format.” Accessed April 11. <https://github.com/google/protobuf/blob/master/README.md>.

———. 2017b. “Protocol Buffers | Google Developers.” Accessed April 11. <https://developers.google.com/protocol-buffers/>.

Internet Engineering Task Force. 2017. “RFC 6455 - the Websocket Protocol.” Accessed April 11. <https://tools.ietf.org/html/rfc6455>.